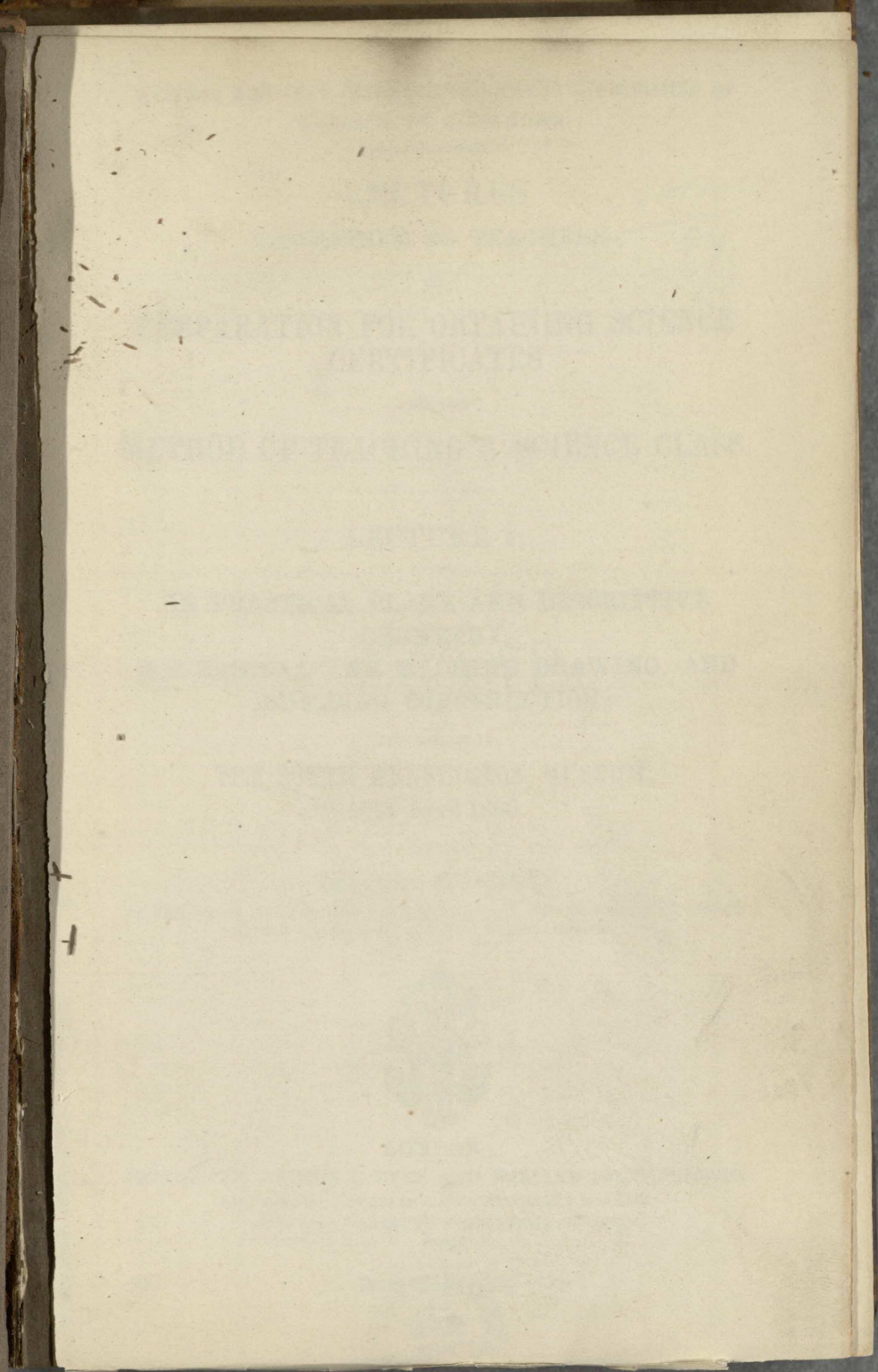




- ✓ Bradley 1
- ✓ Cowie 2
- ✓ Tyndall 3
- ✓ Huxley 4
- ✓ Smyth 5
- ✓ Lankester 6
- ✓ Hofmann 7
- ✓ Ramsay 8
- ✓ Riddle 9
- ✓ Kinkel 10
- ✓ Donnelly 11







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Science and Art Department of the Committee of  
Council on Education.

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LECTURES  
ADDRESSED TO TEACHERS  
ON  
PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES  
AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE I.

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ON PRACTICAL PLANE AND DESCRIPTIVE  
GEOMETRY,  
MECHANICAL AND MACHINE DRAWING, AND  
BUILDING CONSTRUCTION;

DELIVERED AT  
THE SOUTH KENSINGTON MUSEUM,  
16th April 1860.

BY  
THOMAS BRADLEY,  
OF THE ROYAL MILITARY ACADEMY, WOOLWICH, AND PROFESSOR OF GEOME-  
TRICAL DRAWING IN KING'S COLLEGE, LONDON.



LONDON :

PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,  
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1860.





Scientific and Art Department of the Committee of  
Council on Education.

# LECTURES

ADDRESSED TO TEACHERS

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE

METHOD OF TEACHING A SCIENCE CLASS.

## LECTURE I.

ON PRACTICAL PLANE AND DESCRIPTIVE  
GEOMETRY,  
MECHANICAL AND MATERIAL DRAWING, AND  
BUILDING CONSTRUCTION.

THE SOUTH LONDON MUSEUM.

1880.

THOMAS BRADLEY.

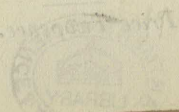
OF THE ROYAL MILITARY ACADEMY, WINDSOR, AND PROFESSOR OF CIVIL  
ENGINEERING IN THE ROYAL COLLEGE OF SCIENCE, LONDON.

LONDON:

PRINTED BY GEORGE E. HINE AND WILLIAM SPOTTISWOODE

PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY  
FOR THE NATIONAL STATISTICAL OFFICE.

1880.



## LECTURE.

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THE term drawing is generally applied to a pictorial representation of objects, the apparent forms of which, traced on paper by the Artist, being made more imitative or suggestive of the originals by the addition of light, shade and colour; this definition is not applicable to the work of the geometrical draughtsman—he represents certain classes of objects of their real forms and proportions, the drawing being intended to enable the workman to construct the object; to effect this, distinctness and accuracy are the only indispensable requisites. The working drawings given to the bricklayer, mason, and carpenter who build the house, are very unlike the attractive view of the future mansion, with its surrounding scenery, laid before the proprietor by the architect.

The same name has been given to these very different representations simply because the same materials are used in their production: but this is all that they have in common; pleasure and not utility is the result of the artist's labours; mere utility, that of the draughtsman's.

I shall throughout this lecture use the terms pictorial and graphical to distinguish the two classes of representations. I call that pictorial which suggests to the mind the real object, by showing its forms as they appear to the eye: the graphical representation does not show the apparent form, and can only suggest the thing represented to a mind trained to interpret rightly the mode of representation.

The drawing which we are about to consider, being always intended to represent geometrical forms, must be based on an application of geometrical theorems; but the practical geometry of the draughtsman differs somewhat from that of the mathematician; the modifications being necessitated by the use of rulers, compasses, and other mechanical aids not recognised in the science, and consists in selecting, from two or more constructions that would be applicable, the one which requires the fewest steps, and those best adapted for the application of the mechanical aids mentioned; but it is, of course, to be understood that no modification is admissible, which is incompatible with rigorous demonstration.

The geometrician considers an indefinitely extended straight line as completely determined by two points in it, however near these may lie to each other as long as they are not coincident,—the draughtsman, of several constructions for determining such a line, always adopts that which will give him two points in it as far apart as circumstances admit of their being found; for his lines have perceptible breadth, and their intersections are so far from being the points of geometry, that more than one line may be drawn which would seem to pass through two of his points, of which one must, and possibly both may be, wrong.

This distinction between the practical application and the theoretical problem, may be further illustrated. The draughtsman rarely employs even a modification of the construction given by Euclid for dividing a line into any proposed number of equal parts, but divides the line by a few trials with his dividers; knowing that by so doing he secures a more accurate result than he could do by the problem which involves two intermediate steps, each likely to introduce an



error; and this method, by mechanical division by trial, is rendered still shorter and more certain, if the proposed number can be resolved into two factors; in which case the line being divided by trial into the number of equal parts expressed by either factor, each such part is again subdivided into the other number of parts.

If a geometriician objects to such a proceeding as incapable of demonstration, and were to state that it might be drawing, but certainly was not geometry, let him explain how a circle is to be described, from a given point as a centre at any distance from the centre, except by the use of a pair of compasses or some equivalent aid, which tacitly implied the equality of the radii.

It has been stated that accuracy is an indispensable condition in geometrical drawing; but accuracy is a relative term and no definite rule regarding it can be given. A drawing of the timbers of a floor or roof is accurate if it do not mislead the workman half-an-inch in twenty feet, while an error to the same amount in the drawing of the slide valves of an engine, or of the escapement of a chronometer, would render it useless. But it may be safely asserted that no error visible to the eye should ever be passed over by a beginner; by a resolute adherence to this precept, he will soon attain the power of drawing with all attainable accuracy, with as much readiness as if he were negligent in this respect.

The first step towards the attainment of accuracy in drawing, is to make every construction, or part of one, on as large a scale as is practicable. The next to have all the instruments in the best order, and to keep them so, and to be able and accustomed to verify them from time to time; it does not follow that what looks like a ruler should have a straight edge and admit of a straight line being drawn by means of that edge, and both rulers and compasses must be properly handled; and further, no accuracy can be secured without the utmost neatness and delicacy in operating.

No useful remarks on the elementary constructions of geometry, involving the straight line and circle only, can be given in the course of a brief lecture; but some must be allowed regarding the curves occurring in other constructions. We possess few mechanical means for tracing such curves as the conic sections, cycloids and epicycloids, spirals and others, constantly required in drawing; all that is in our power is to determine a sufficient number of points in the curve, from its geometrical properties, to enable us to trace the curve through them; the steadiness of hand and accuracy of eye required to do this can only be acquired by practice: the want of this skill induces draughtsmen to endeavour to substitute a combination of circular arcs of different radii for the true curve. This proceeding is most objectionable; if the curve enter into any construction depending on it, the substitution is fatal to accuracy of result; and if it form part of any architectural design, it is equally repugnant to taste. The elliptic arch of a bridge cannot be represented by the combination of arcs called an *oval* in ordinary books; the spiral of the Ionic volute in classical architecture is totally unlike the combination of quadrants of circles described from successive centres, given in works of carpentry; and I may venture to suggest that the contour of a gothic arch in the best cathedrals is not a circle, but another curve of varying curvature, and consequently more pleasing to the eye.

Most works of which geometrical drawings are required are *symmetrical*, or consist of equal and similar parts, similarly placed with respect to a central line or axis, and the subordinate parts of such works are also symmetrical to secondary axes. These central lines



never appear in the work or on the drawing representing it; yet they are the first lines that should be drawn, for on them depends the accuracy of the result. Learners, when essaying to draw any piece of mechanism or building, neglect this precaution: not seeing these axis-lines on the copy before them, they begin by drawing those lines which are seen as forming the work, instead of those on which the symmetry or uniformity of the design depends.

Although architectural drawings more especially require attention to this rule, yet it will be found not less necessary in drawings of machinery of all kinds. The central axis of the cylinder of a steam engine or pump is equally that of its piston and its rod, of the stuffing box, cap, &c.; and all these parts cannot be properly adjusted to each other by any attempt to draw them independently of the central axis.

In architecture, the principle extends even to the centre lines of windows, doors, niches, and other parts, as much as to the central line of a portico, and again of this to the central lines of each column.

This proceeding is a practical application of the geometrical principle of co-ordinates, which with equal numerical values have their positions with respect to the axis of abscissæ, indicated by positive and negative signs; and by the draughtsman it is often extended to concentric circular ordinates, as in copying the profiles or outlines of the teeth of a spur wheel, which are thus made precisely the counterparts of each other on each side the central line of the tooth directed to the centre of the wheel.

In drawing any machine, or part of one, that causes motion or change of position, in one or more connected parts, it is essential that the beginner should satisfy himself that this condition of mutual action is possible in his figure. The drawing can, of course, only show all the parts at rest in one position; and the inexperienced eye may not detect some error, in the length of a lever, in the distance between two centres of motion, or in the form of a cam, that would cause a dead lock or stop to the action the moment the machine began to move. In order to satisfy himself of the possibility of a smooth, continuous motion of the engine, the draughtsman represents, on the same figure, the leading moving part in two or more new positions; and by thence deducing those of all the consecutively dependent parts, he can detect any error in his forms or lines which may exist in the design as regards the mechanical action.

Suppose the beginner wished to draw the section of a condensing engine, always a popular subject, he should not be allowed to copy the drawing placed before him; but by beginning with the piston at a different part of its stroke in the cylinder, he should be instructed to represent the necessary change of position, in succession, of the slide valves, the excentric, crank, and crank-rod, beam, parallel motion, back to the piston again and the simultaneous change of the piston of the hot water pump, and, connected with this, of the valves through which the water is returned to the boiler.

When making these exercises, the student should represent no details of construction—these must be drawn and studied apart—he had better not even indicate the framework, or, at most, but slightly; but, devoting his attention to the principle and action of the engine, he learns principles of mechanism in addition to the art of drawing.

Since it is in machine drawing that the greatest nicety and accuracy of construction is required, I may here caution the learner, who wants to become a good mechanical draughtsman, not to be ambitious of drawing whole machines or engines before he has had



sufficient practice in those component parts which recur in many and totally different arrangements: it is not sufficient to make a pleasing looking outline of a machine unless all its parts have that proper relation of size and connexion essential to their true mutual action. He should, therefore, draw those parts which are found in all mechanical combinations, such as pillow blocks, axles frames, couplings, wheels, drums, rods, and other detached parts until he is well acquainted with their general forms, proportions, and uses; for every beginner necessarily looks forward to a time when, no longer required simply to copy a drawing set before him, he will be expected to design and arrange a combination of such parts to form a machine calculated to execute some specified work.

The representation of any object is generally less than the object itself; the ratio between the lines of the former and those of the latter constitutes what is called the "scale of the drawing," and this ratio is, or should be, always expressed on the drawing in one of two ways; either by a line divided into equal parts, each representing the unit of length, and its subdivisions, by which the object itself is measured, or else, by a numerical fraction, expressing that ratio; this latter is the preferable proceeding, since it is understood wherever the arabic numerals are used. Thus, if one side of the *plan* of a room is five inches, while the room itself is 40 feet long, the fraction would be  $\frac{1}{8}$ ; for 96 inches is represented by 1 inch. A Russian, therefore, seeing that fraction on the drawing, could tell the dimensions of the room, by using his unit of measure, the *verschock*, and multiplying the number by 96 he ascertains those dimensions in terms with which he is familiar, while he may never have heard of an English foot or inch.

It is accordingly an essential part of the course of instruction to teach the beginner how to draw scales of every kind of unit, domestic and foreign, and to assign to any drawing its "*comparative fraction*" as it is called. He must also be taught the construction and principle of diagonal scales: obvious as are the calculations and constructions required for these purposes, beginners are often at a loss to understand them without careful explanation.

The objects represented in drawings are solid, or possess length, breadth, and thickness; and it becomes a question how can we indicate the true forms of any such solid in these three directions on a flat surface, such as a sheet of paper? but to put the question in a more general form, how can we express the surfaces of such solids, being portions of planes or curved ones, so as to give their true forms? If by plane geometry we can draw a circle to pass through three points, how are we to draw a sphere on which four given points shall be situate? How can four points, not lying in one plane, be represented on paper? And how are we to express an indefinite plane that shall touch that sphere in any proposed point? Every person can answer readily the former of these questions; for most are familiar from childhood with some kind of geometrical drawings, designs for buildings at the exhibition of the Royal Academy, and prints of machinery and other structures in books; and so familiar are they with these that they would be surprised if asked on what principle such drawings were made, while many could not give a satisfactory explanation of the mode of representing the sphere and its tangent plane though done by precisely the same principles.

The collective theorems, and their application employed for this purpose, constitute what is called Descriptive Geometry, a title taken from the French who are the principal writers on the subject.



It would, perhaps, be better to term them practical *Solid Geometry*, as bearing to the theoretical geometry of planes and solids the same relation that our practical plane geometry bears to that of lines and plane figures.

To give an idea of the first principles of Descriptive Geometry let us take a very simple example. Suppose we wanted to represent a rectangular box so that a workman could make it from our drawing. We imagine three planes, each perpendicular to the other two, and the box placed with each pair of its sides or faces parallel to these three planes. If we suppose the edges of the box prolonged in their directions so as to cut these planes, and the four points on each joined, we should have on each plane a rectangle of the same dimensions as those of the faces of the box to which that plane is parallel; each of these rectangles is termed an *orthographic projection* of the box on that plane; and to distinguish them that which showed the length and breadth is called a *plan*; that in which the length and height were represented is an *elevation*, as showing that height or altitude; while the third figure, giving the breadth and height, is distinguished by the name of *end elevation* or *profile*.

It is clear that the length of the box would be represented both in the plan and elevation, its breadth would appear both in the plan and profile, while its height would be shown in both elevations; and in each figure those edges which were perpendicular to its plane would be represented by points only. The dimension in those directions, therefore, could not appear in either of the figures; hence the necessity for two such projections at least in order to show the dimensions of the box in all three directions.

The three projections, the plan, elevation, and profile, are drawn on one paper by imagining that each of the two vertical planes has been turned round on its intersection with that supposed to be horizontal till they coincide with that plane; this supposed rotation of a plane on its intersection with another till they coincide is the foundation of all practical Solid Geometry.

In the drawings made to guide workmen, the three planes just described are assumed as parallel to the principal planes of the structure to be represented, for these are usually mutually perpendicular; as, for example, the front and end walls of buildings which are vertical, and the planes of the floors which are horizontal, the rectangular forms of the building, such as its doors, windows, and other parts, are shown in the elevation as rectangles, similar to the originals, or are projected into straight lines on the plan. But it must not be supposed that this is always, or necessarily the case; many parts of all works, even of buildings, are neither vertical nor horizontal, and therefore not parallel to either of the rectangular planes of projection, and consequently cannot be represented of their true proportions. It is necessary, therefore, that the learner should acquire the power of representing any forms situate in any position with respect to each other, and to the planes on which they are to be supposed projected: the constructions for accomplishing this constitute the elementary part of practical solid geometry.

But we should be able to accomplish very little in the way of representing structures of any kind, if we could only delineate solids bounded by plane surfaces, and having straight edges: forms are far from being as simple as those of the box we began with supposing as the object to be represented; they generally consist of indefinitely varied combinations of plane and curved surfaces, and, therefore, having curvilinear edges which must be determined on the drawing with the same precision as the straight line, and equally



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depend on the same general principle of supposing all the points of the original curve *projected* on two rectangular planes by lines called projectors, perpendicular to those planes.

It is also often necessary to indicate the geometrical nature of surfaces (not planes), irrespective of any lines which are their mutual intersections. This necessity does not present itself as long as the edges are straight lines, however numerous or complicated; for their representations on the drawing being also straight, the mind infers that the surfaces bounded by them are planes. How are we to express on paper surfaces which are curved? The obvious answer would be that this could be effected by means of light and shade, as is done in ordinary drawing. But effects of light and shade cannot be determined by geometrical rules, and are therefore inadequate to define a surface in a geometrical drawing.

All surfaces can be conceived as being formed by the continuous motion of some kind of line. In elementary books of geometry, a cylinder is described as being *generated* by the motion of a rectangle round one of its sides, as a fixed axis of rotation; and a sphere, by the motion of a semicircle round its fixed diameter. By this definition, or description, is merely meant that *if* such a line moved in the manner described, it would, in all its positions, lie wholly on that surface. Extending this conception, we can imagine every possible kind of surface generated by the motion of some kind of line or other, variable or constant, that motion being governed by some condition or law. This moving line is called the *generator* of the surface.

In geometrical drawing, a surface is rigorously defined and expressed by the projections of its generator in a series of consecutive positions. And, since all surfaces admit of more than one law of generation, that one may always be chosen, the projections of which admit of most easy construction. Nor is it by any means necessary to draw the generator in an indefinite number of positions; as many only need be employed as are sufficient to express the surface, or to make any subsequent construction relating to it. And it is often necessary to combine two systems of generators in one figure, to determine or define more explicitly complicated surfaces.

It may be thought that this principle of representing surfaces is of no practical use in the arts of construction, since, in ordinary working drawings, surfaces are seldom thus represented; for, being plane, they do not require to be defined, as has been mentioned. To show that this is an erroneous opinion, I will call your attention to some occasions on which it is necessary to express, on a geometrical drawing, surfaces by means of their generators.

There are many to whom, although familiar with maps of all kinds, it has never occurred that the meridians and parallels of latitude, which constitute the essential groundwork of the representation, are in fact the generating semicircle of the sphere in successive positions, combined with another system of generation by a circle of variable radius, moving with its centre in the fixed diameter of the semicircle assumed as perpendicular to the plane of the moving circle. These generators are graphically represented in different manners by the principles of descriptive geometry, according to the purposes for which the map is wanted, and to the extent of surface to be represented.

Of all the surfaces that occur in works of human labour, that of a vessel of any kind is the most varied, and certainly the most important. The working drawings made to guide the shipwright represent this surface by the projections of two series of horizontal and



vertical sections of the hull by equi-distant parallel planes; the varying curves of these sections are, in fact, representations of a generator varying in form according to some law, dependant on the requirements of the vessel for speed, tonnage, and so on; these curves, drawn to full size on the floor of the *moulding-room*, as it is called, enable the wright to cut out templets or moulds in wood, by which he forms the ribs and planking of timber ships, or the sheet-iron covering of the iron frames of iron vessels.

When screw-propellers were introduced, it was a new problem for draughtsmen not well conversant with descriptive geometry to represent the surfaces required, which belong to a class called *ruled*, only capable of representation, even when simple, by their generators, and far from simple in the case of these propellers. And another instance is afforded by the construction of the arch of an oblique bridge, carrying a railroad over a common road, and crossing it at an oblique angle. Each stone of such an arch has six surfaces, not one of which is plane; those which lie in the soffit and back of the arch are portions of cylindrical surfaces, while the two sides and ends are portions of ruled surfaces, like that of the screw propeller, but different for the sides and ends, and an elaborate construction is necessary to make the working drawing to guide the mason in working these *voussoirs*. In this country brick is so generally used in building that our workmen do not require the same extent of knowledge which is necessary in countries where stone is employed. In France, for example, a large section of every work on descriptive geometry is devoted to the graphical determination of the forms of stones entering into every kind of arch, vault, or roof, and their intersections by apertures for doors, windows, embrasures in casemates, and other purposes; this branch of the subject is technically called "*Coupe de Pierres*," and is familiar to the foreign workmen who require it. Many of the surfaces occurring in these constructions are complicated ruled ones, which must be shown on the drawing by their generators, in order to define the curves of their mutual intersections.

By the same general principle, of the representation of surfaces by lines, we can express those which are not geometrical: this is done in topographical drawings representing on a large scale portions of the surface of the earth, the varying undulations and heights of which are shown by means of a series of horizontal sections, supposed to be made by equidistant planes, the plans of these sections being called *contours*: a sufficient number of points at the same successive levels on the *ground* are determined by actual survey; these points being plotted on the drawing, the continuous curved lines are afterwards filled in by a system of interpolations which it would be foreign to our subject to dwell upon.

The greater part of England and Ireland has been thus surveyed, and the counties mapped by contour lines in the execution of what is known as the Ordnance survey, which has been in progress for the last 60 or 70 years; and within a few years London and its neighbourhood was surveyed and contoured more accurately for sanitary purposes.

On plans of ground thus shown by contour lines, earthworks, such as embankments, cuttings, and tunnellings for railways, and other roads, are designed and expressed with more precision than they can be in any other mode; the artificial surfaces, usually plane ones, being represented by the equidistant straight contour lines in which these surfaces would be cut by the imaginary horizontal planes before mentioned, by which the contour lines of the ground itself were determined.



It is to the military engineer, perhaps, that the representation of ground by its contours is most valuable. In the practice of fortification it is necessary to design works temporary or permanent which shall protect the garrison from the enemy's fire, and at the same time enable it to annoy that enemy on whatever side he may attempt to approach. The earth of which these offensive and defensive works are made, by being dug, forms the ditch, which so materially adds to the strength of the work. The ground within the place may require levelling, and artificial ground has often to be made outside, partly by filling up hollows, to prevent them from affording cover to the enemy, and partly to bring him more completely under the fire of the garrison. All these various and often conflicting demands necessitate elaborate constructions which can only be executed on ground shown by contour lines.

Although, as I have stated, light and shade is inadequate to express surface with geometrical precision, it is often employed in drawing to assist the mind through the eye in conceiving the forms represented.

Whatever shading for this purpose is added to the outline of a working drawing should be solely for the purpose of making it more intelligible, and not at all for pictorial effect, for such a proceeding would be an attempt to combine incompatible conditions, since the outline or form cannot be pictorial owing to the purpose for which such drawings are made, and to the principles on which they are made. The beginner should therefore never let his ambition of improving the appearance of his drawing, as he fancies it would do, get the better of his judgment on this matter.\*

But even in working drawings it is advisable to distinguish cylindrical or any curve surface by a graduated tint, adapted to indicate the surface, provided this shading is so light and delicate as not to conceal the outline, and that the tinting is consistent in its gradations and forms with the surface on which it is employed: thus, if the surface to be tinted is to be shown as that of a sphere, the gradations must take place in the circles, or the elliptic projections of the circles, in which the imaginary cylinders containing all the rays of light which would fall on the sphere at equal angles would intersect the sphere; for if this precaution is neglected, the tinting is better omitted. If the surface is a conical or cylindrical one, the gradations in the shading must be in the straight generators, for the rays which fall on those surfaces at equal angles must lie in planes which would cut the surface in its generators.

In geometrical drawings it is usual to tint all plane surfaces inclined to the plane of projection, the depth or tone being proportioned to the degree of the inclination; but, as there can be no connexion between inclination and tone of shade, much must be left to the judgment of the draughtsman. What has been just described as to the shading of curved surfaces is an immediate consequence of this rule regarding planes; for if the curved surface be conceived as a polyhedron, the *facets* of which are indefinitely minute, the facets being shaded in proportion to their inclination, the result would be most correctly that of the surface itself. For example, a cylinder and cone may be considered as a prism or pyramid of an

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\* At the delivery of the lecture, this point was enforced by the exhibition of some elaborately shaded prints and drawings of machinery, and the consequent indistinctness of form and mode of action of the engines was pointed out. It may be here mentioned that throughout the lecture, reference for illustration was made to drawings and diagrams prepared for that purpose; it not being deemed expedient to publish reduced copies of these in a printed work, many alterations in the arrangement and wording of the discourse have been necessary.



indefinite number of sides, and a sphere as a solid of an indefinite number of minute plane faces, symmetrically placed with regard to the plane of projection.

And as it is usual in sectional working drawings to express the different materials of the structure by conventional colouring, as red for brickwork, yellow for timber, blue for iron, and so on, the learner must acquire the power of using a brush to lay on flat tints of some extent and to gradate them to express curved surfaces as just explained. The best mode of learning the use of the brush is to draw by eye forms of white earthenware, such as cups, jugs, basins, and then to imitate with the brush the delicate gradated tints the objects present to the eye, for any tinting in a drawing is more or less to be governed by the principles of art.

There is one mode of applying the principles of orthographic projection which should be well understood from its great practical utility. When the three rectangular planes forming the adjacent faces of a box, like that which was before mentioned, are supposed to be equally inclined to one of the planes of projection, the projection of that box on that plane is said to be *isometrical*, for the three edges must also necessarily be equally inclined to the plane, the projections of those edges, and of all lines parallel to them, will be to each other in the same ratio as the originals, the dimensions of the object can therefore be determined from the projection in those three rectangular directions by means of a scale adapted to the purpose on the drawing. Let us suppose the box to be 15 inches long, 10 inches broad, and 7 inches deep, those edges projected isometrically will on the drawing be  $10\cdot5 : 7 : 4\cdot9$ , which are in the same ratio as the originals, the scale must therefore be so constructed as to indicate 15 inches as the measure of the longest edge.

The advantages of using isometrical projection are that like all projections which, suppose the faces of the object not parallel to the planes of projection, all three faces of a solid, like the box, can be shown in one figure, instead of requiring detached figures of plan, elevation, and profile, hence the arrangement of the several parts of any structure can be more clearly understood from the isometrical projection, than from an ordinary one; but the principle of equal proportions only being true of lines parallel to the three rectangular edges of the solid, objects alone which consist of forms generally rectangular, such as buildings, floors, framings, and so on, can be advantageously shown by this method. Of course all circles, the planes of which are rectangular or parallel to the principal planes, will be projected into similar ellipses, and the two principal axes of these ellipses will be to the diameters of the circles themselves as  $\sqrt{3} : 1 : \sqrt{2}$ . Hence these axes are readily determined in magnitude; but the trouble of drawing these ellipses has hitherto prevented any extended use of isometrical projection in making working drawings, and workmen are not as yet trained to understand such a representation; but from its utility, its employment is increasing, especially by the corps of Royal Engineers.

The geometrical surfaces which form those of structures of all kinds are not very numerous; the number is limited by our power of forming smooth or continuous surfaces by mechanical action. The plane, being that of most universal occurrence, some of our most elaborate tools are those for planing iron or other materials, the word implying that the object of the machine is to produce a plane or flat surface.

By the familiar operation of *turning* we are able to produce a class of surfaces of the greatest importance in the arts; the mathematical



term for this class is "surfaces of revolution," the characteristic definition of them being, that all sections of them made by planes perpendicular to the axis of revolution are circles.

The common cone and cylinder are familiar examples of geometrical surfaces of revolution; but besides these two there is a variety of surfaces, which though not surfaces of revolution, must be included in the same family with them, they being capable, like the ordinary cone and cylinder, of being generated by the motion of a straight line, either always passing through a fixed point, or else always moving parallel to a fixed straight line. This class of surfaces admits of a plane figure being made, which would exactly coincide with the surface, if rolled round it. The branch of descriptive geometry which teaches us how to produce such a plane figure is called *development*, and is one of the most practical importance. By means of it the boiler-maker can so fashion a flat sheet of iron, that it shall correctly form part of a cylindrical boiler. The cabinet maker cuts his veneer to cover a curved surface; the tin plate worker by means of the same constructions forms the body and spout of a coffee pot; and so on. But perhaps the maker of models has recourse to them in more frequent and various cases than even those operatives.

But you must not mistake the definition of developable surfaces, and apply it to other surfaces of revolution, for the sphere, the commonest of all, is not capable of it; hence the practical impossibility of covering a common globe with flat paper, bent to coincide with it. Nor, on the other hand, do all surfaces generated by the motion of a straight line admit of it. Those which are so generated, and yet do not admit of development, are termed ruled surfaces, of which that of the screw and of the propeller of a steam vessel are common instances.

Every one present is familiar with the term *perspective*, and has some idea of its connexion with geometrical drawing. It is in truth another mode of representing on a flat surface solid bodies, bounded by geometrical forms. Orthographic projection has been defined as the projection of lines and points by means of planes and lines perpendicular to the plane of the paper, or by means of parallel projectors, forming a complex *prism*, the section of which is the projection of the points and lines from which these projectors emanate. In perspective projection, the lines by which the projections of points are determined meet in a point, and thus form a complex *pyramid*, the section of which is the projection required.

The term *perspective* was early applied to this kind of projection; because if the point, or vertex of this pyramid, be supposed to be at the eye of a spectator, the lines of the projection would appear to him to coincide with the edges of the original object, and would therefore present a true *pictorial* outline of that object. To determine on paper by geometrical construction the section of such a pyramid of imaginary projectors, requires a perfect knowledge of orthographic projection, and more in addition; it is a mistake, although a common one, to suppose that it is easier to acquire a knowledge of perspective, as it is termed, than of orthographic projection. The two branches of practical solid geometry never can be separated; but if learnt in succession, the projection by parallel projectors must precede, as far easier to understand and practice, than that by converging projectors.

To explain what may appear an assertion contrary to the experience of many, I must remind you that perspective projection is chiefly, though not solely, used by architects, who by means of it



can determine the apparent future forms of structures not yet existing, such as that of the house I alluded to at the commencement of this lecture. But to do this they require only the simplest case of the constructions; the principal lines of the building being vertical and horizontal, they assume their plane of projection, or "of the picture" as it is commonly termed, as vertical also, and thus greatly facilitate the making of their drawing. This assumption causes their operations to bear to the general problem the same relation that the ordinary plan and elevation, such as of the rectangular box, bears to any oblique projection of the box.

It must be understood that the perspective projection of a geometrical solid does not rigorously suggest to the mind the same idea or perceptions of forms that the original would do, if viewed from the precise point of convergence of the rays or projectors; the difference arises from the laws of vision, the limited field of view the eye can take in at one time, from the fact that we look with two eyes, and from many other causes connected with physiological phenomena foreign to our subject.\*

The geometrician determines, demonstrably, the section by a plane of a pyramid of projectors proceeding from all the points of a solid to a common vertex. The artist takes as much of the result or of the means for procuring it, as suits his purpose, determining the position and distance of the "point of sight," as he calls the vertex of the pyramid, from the "plane of the picture," so that the image, or projection, may not be distorted or appear unnatural: his power of drawing enables him to fill in the detail with little further aid from geometrical construction; but having connected the term perspective with a purely geometrical problem, he conceives there must be some error, or inconsistency in the, to him, extraordinary results at which the draughtsman arrives; if, however, each understood the meaning and object of the other, there could be no more of this misunderstanding, and I may be permitted to observe that what the geometrician does is as demonstrably correct as any proposition in Euclid, while the artist cannot always palliate the strange errors he often commits in delineating purely geometrical forms by eye or from memory.

Perspective projection is essential in the construction of maps, the determination of shadows, and is used occasionally by others than artists and architects; but as it is not employed in making working drawings it need no longer detain us, especially since we have numerous and excellent works treating fully of its principles and practice.

Considerable difficulty is frequently experienced by learners, in understanding and applying the principles of projection; this difficulty is not inherent in the subject itself, but arises from the want of previous mental training by a sufficient study of theoretical geometry, which enables the student to conceive in his mind the relations of magnitude in space. The just preference for analysis, as the most powerful agent in mathematical investigations, causes the neglect of pure geometry in all our schools and colleges, in which boys

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\* The mind judges of the form, direction, and magnitude of objects chiefly by the angles, plane or solid, they subtend at the eye; the connexion between the angle subtended, and the real direction and length of the line or form of the surface, being the result of that chain of reasoning and inference which, become instantaneous from constant practice, originally occupied the mind with a succession of acts of its faculties; for these *mathematical* judgments regarding magnitude are further complicated by the perceptions of differences of colour or aerial effects, as an artist would term them, which contribute to the ultimate effect on the mind of the spectator. It is clear that the geometrician's perspective can have no reference to these mental processes.



learn only the first few books of Euclid, and that very superficially, while the eleventh, the most important to the future draughtsman, is rarely looked at in youth, and if it is occasionally read, the diagrams employed to assist the reader in following the demonstrations tend to produce erroneous impressions in his mind which it costs some effort subsequently to rectify. Every teacher must have noticed that his pupils can only conceive a plane as bounded by four lines, and as either horizontal or vertical, from seeing the diagrams always representing a plane in that manner; they consequently cannot readily understand why in practical solid geometry an indefinitely extended plane can only be graphically expressed by the projections of some lines which necessarily lie in it; and although they readily admit the necessity for both a plan and elevation of any structure, as a house or a machine, in order to define its dimensions of length, breadth, and thickness, yet they cannot perceive the equal necessity for two projections of every point, line, or plane figure abstractly considered; and the consequent double data for a few points, lines, and planes causes a complexity of lines on their drawings which adds to their embarrassment.

Let the beginner draw a circle on his paper and then consider how many different things that circle may represent: if it simply means a circle in the plane of the paper, it requires nothing to make it significant, and any construction may be made regarding it by the propositions of plane geometry; but the circle may represent a sphere, a right cylinder, or cone having their axes perpendicular to the plane of the paper, and many other things besides. To make the circle fully express any of these surfaces a second figure is necessary, which is the projection of the sphere, cylinder, or cone on another and vertical plane. After drawing this second figure or elevation, let the learner propose to himself some construction regarding the surface, such as drawing or representing a plane tangential to or cutting the surface according to some condition; his attention is thus drawn to the mode in which he can express a plane without reference to any line or figure in it; he will on reflection arrive at the conclusion that he can only do so by means of the line or lines in which that plane would cut the paper, and the assumed vertical plane; to determine these *traces* of the plane as they are called, so that the plane they define or fix may comply with the required condition, requires a knowledge of the propositions regarding planes and lines, as a foundation for the graphical constructions necessary, and the best mode of learning either is to study them together. Even at this stage the learner has made some progress in acquiring ideas on the subject of solid geometry, but let him not lose the ground he has gained by looking at his drawing as only so many pencil lines on a sheet of paper; they must be for him a sphere, cylinder, or cone, and he must force his imagination so to view them: the solid must be one for him having rotundity and volume: by a similar proceeding with a simple solid bounded by planes, such as a cube, prism, or pyramid, let the learner endeavour to represent its edges when they are supposed not to be either parallel or perpendicular to the planes of projection; he cannot draw the plan and elevation arbitrarily, but must determine the projections with reference to the assumed position of the solid with respect to the paper and to the relations existing between the lines themselves. He will now find himself obliged to study the elementary problems on the constructions in solid geometry, and gradually to combine these till he can represent his cube in any position. If he become interested in the study, and has resolution to proceed in



Box 1

mastering the difficulties he will necessarily meet with in a, to him, new pursuit, his progress will be steady if slow ; but if he is impatient, because what he is drawing does not resemble anything, and therefore appears useless to him, he will remain a mere copier of drawings of buildings, machinery, or constructions which he certainly does not rightly understand.

Many persons imagine that descriptive geometry is a new science of modern discovery : it is true that it was only at the end of the last century that the French geometrician F. Lacroix for the first time embodied in a work the principles and practice of the art, which had been scientifically developed by his friend and master, Monge. But practical solid geometry, as it has been defined in this lecture, must have existed from remote ages, and in all civilized nations. It is impossible to suppose that the temples of Egypt, Greece, or of India, and the magnificent and more elaborate ecclesiastical structures of the thirteenth century, throughout western Europe, could have been executed without drawings. How could masons prepare a stone, weighing some hundredweights, to fit exactly in the vaulted roof of a cathedral, without such a knowledge of descriptive geometry as should enable them to determine its several services with all the precision requisite for its adaptation to its place.

It was, we know, this skill, taught secretly to their apprentices by the masons and others in the middle ages, that constituted the bond which united them in those guilds and fraternities of which traces exist to this day. And it is the weight and size of the material on which he operates which compel the mason to be the most careful and scientific of all operatives.

The knowledge of descriptive geometry possessed by many other artisans is equally due to their having to operate on solid matter, these operations supplying to their minds those conceptions the mathematician is often deficient in :—the carpenter in framing timber, in getting out and glueing up the mahogany for the spiral hand-rail of a staircase,—the mason cutting a stone,—a smith forging iron,—the turner turning a bed-post—all learn a geometry of a most valuable, though not very scientific, kind, and are thus enabled to invent for themselves methods of determining forms, and making constructions regarding them, often unknown to their employers.

The term “utility” is so constantly used in England as the object of all intellectual exertions that I have principally endeavoured to point out the *utility* and indeed necessity for a knowledge of geometrical drawing to all who have to direct structural operations in arts and manufactures ; but I might have taken a higher position and have dwelt on the intrinsic pleasure in the pursuit that must be felt by all capable of appreciating mathematical truth. To those accustomed chiefly to the symbols of that science, it is gratifying to have the results of their investigations presented to their contemplation by the aid of sight as well as of pure reason ; and surely we should pause before treating superciliously, as useless to all but carpenters and masons, a branch of science that has been treated of and explained by some of the greatest mathematicians who have added lustre to a nation holding the highest rank in all intellectual pursuits.



mastering the difficulties he will necessarily meet with in a new pursuit, his progress will be nearly if not entirely unimpeded, because what he is doing does not resemble anything, and therefore appears new to him, so will remain a mere copy of drawings of buildings, machinery, or contrivances which he certainly does not really understand.

Many persons imagine that descriptive geometry is a new science of modern discovery; it is true that it was only at the end of the last century that the French mathematician M. Lacroix for the first time embodied in a work the principles and practice of the art, which had been scientifically developed by his friend and master, Monge. But practical solid geometry, as it has been defined in this lecture, must have existed from remote ages, and in all civilized nations. It is impossible to suppose that the examples of Egyptian, Grecian or of Indian and the magnificent and more elaborate ecclesiastical structures of the intermediate countries throughout western Europe, could have been executed without drawings. They could scarcely prepare a stone, weighing some hundredweight, to its exact fit in the vaulted roof of a cathedral, without such a knowledge of descriptive geometry as should enable them to determine the several services with all the precision requisite for its adaptation to its place.

As we know, this skill taught nearly to its perfection by the masters and others in the middle ages, that constituted the bond which united them in those trials and adventures of which there often is to this day. A knowledge of the weight and size of the material on which the architect was to operate, was most essential to the success of his operations.

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Geometry is equally essential to all solid matter, these operations applying to their minds those conceptions the mathematician is often obliged to—his capacity in drawing, in getting out and raising up the machinery for the spinning hand-loom of science—the master cutting a stone—a smith forging iron—the farmer towing a bed-post—all learn geometry of a most valuable, though not very scientific kind, and are thus enabled to invent for themselves methods of determining forms and making constructions requiring them, often unknown to their superiors.

The term "utility" is so commonly used in England as the object of all intellectual exertions that I have principally endeavored to point out the utility and indeed necessity for a knowledge of practical drawing to all who have to direct manual operations in arts and manufactures; but I might have taken a higher position and have dwelt on the intrinsic pleasure in the pursuit that must be felt by all capable of appreciating mathematical truth. To those accustomed chiefly to the acquirement of that science it is gratifying to have the results of their investigations presented to their contemplation by the aid of sight as well as of pure reason; and surely we should pause before treating ungratefully as useless to all but carpenters and masons, a branch of science that has been treated of and explained by some of the greatest mathematicians who have added lustre to a nation holding the highest rank in all intellectual pursuits.

Science and Art Department of the Committee of  
Council on Education.

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LECTURES  
ADDRESSED TO TEACHERS  
ON  
PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES  
AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE II.

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ON MECHANICAL PHYSICS;

DELIVERED AT

THE SOUTH KENSINGTON MUSEUM,

23 April 1860,

BY

REV. B. M. COWIE, M.A.

PROFESSOR OF GEOMETRY IN GRESHAM COLLEGE, ONE OF H.M. INSPECTORS  
OF SCHOOLS.



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## LECTURE.

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THE object of this lecture will be to give some hints to teachers who are about to undertake to instruct classes of adults, or young men, in the principles of mechanical physics.

Before passing to this point, however, it is necessary to say something on the necessary qualifications in the teacher himself.

The outline of the acquirements which are considered necessary, is given by the syllabus of subjects in which it is proposed that all teachers should be examined for a science certificate. I will first of all, then, make a few remarks on that syllabus.

You will observe that it has been divided into two parts; in the first of which special attention has been paid to this object, viz., to secure a mathematical acquaintance, more or less extended, of the *principles* of natural philosophy.

In the second, we wish to secure that you should know how these ascertained results are *applied* in various ways practically by the machinist and the engineer, in all trades where mechanical skill is required, or in those grand operations of nature which all proceed upon fixed and invariable laws, whose *elements* you will have already mastered.

And I have ventured, to the horror of those who would restrict *art* to works in which the imagination and the taste predominate, to speak of mechanics as an *art*.

I will merely justify my meaning by the philosophical definition of art:

The object of science is knowledge.

The objects of art are works.

In art truth is a means to an end.

In science, it is the only end.

Without having strictly conformed to this, as indeed the subject does not admit of it, I yet think that it is very fairly allowable to designate respectively as *science* and *art*, the two divisions of the subject which I have described.

To do any real good in the first part of our subject, a candidate must have an acquaintance with pure mathematics; *at least* to the extent of plane geometry, algebra, and trigonometry.

No one can pretend to be able to grapple with the subject unless he have *at least* this amount of pure mathematics.

In order to pass to an extended acquaintance with the vast subject of mechanical philosophy, he ought also to be master of the differential and integral calculus. And, indeed, in order to be sure of his ground in treating those problems which depend on the more elementary pure mathematics, he should know *something* of the calculus, or have familiarized himself with "Newton's method of Limits;" because he will, not without this be able to tell whether a question of mechanics can or cannot be solved without the aid of the calculus. A great range of problems *can* be solved without it, a much greater number *cannot*; and occasionally he may be making fruitless attempts, if, having only knowledge of elementary pure mathematics, he is not aware that the case is one which requires the more powerful instrument.



I should therefore advise all who wish to be sure of their ground, not to rest contented with a knowledge of geometry, algebra, and trigonometry, but to go on from these elements, to gain some knowledge of the methods which have been devised for grappling with the problems of a higher class.

Having secured thus the use of intellectual tools, let me proceed to show how they are to be applied.

Now, in order to bring physical questions under the domain of pure science, it is necessary that certain suppositions or fundamental laws be agreed upon; which are at first *hypotheses* merely, assumed indeed on grounds of experience and observation, but which are *not to be proved*.

In mechanics (proper) this assumption is generally that a force may be applied at any point of its line of action, and produce the same effect.

In dynamics, the three laws of motion, the equality of the impressed and effective forces.

In hydrostatics, that fluids press equally in all directions.

It is of immense importance that the student, and especially one who studies with the object of teaching others, should grasp these fundamental principles with clearness.

None of these principles can be apprehended without clear notions of the meaning of terms. Hence *definitions* and *postulates* at the commencement of any part of a subject should be thoroughly weighed. Time spent on these points is *well spent*. Accuracy and lucid conception are necessary for progress in all subjects, but most especially in mathematical applications, and the adaptation of the results of pure science to the elucidation of natural facts.

The way in which the words *force*, *velocity*, *momentum*, &c. are popularly misapplied, tends to confuse all truth, and instances are not wanting, even in evidence given in courts of justice, of men deposing to utter nonsense, from the loose way of using terms which have a definite and absolutely restricted meaning. This is because persons have derived their knowledge of them from this loose popular sense, and not from the scientific sense. Such words are peculiarly liable to mislead readers who do not take care to understand them in their technical instead of their common signification.

Now you will observe as I go on how all this tends to our main object. What is necessary for a *student* of mechanical philosophy, requires marking with peculiar emphasis by those who have to impress their accuracy upon others—who are to be teachers.

I cannot too earnestly set before you that this dwelling on first principles, and a constant care to be accurate in the use of terms, is beyond measure essential for any real progress in science, is one indispensable condition for securing good results when you attempt to teach others.

When the *principles* of any subject like mechanics for example have been grasped, the rest flows on logically; and there ought to be no difficulty, with the help of pure science, in passing on to any extent. The rest is an exercise of the reasoning faculty. Granted the premises and knowing the use of the tools (for I compare the geometry, algebra, and trigonometry to *tools*), whatever result is *demonstrated* only requires that you convince yourselves of the legitimacy of each step in the deduction, and of the interpretation of your mathematical result into the physical meaning legitimately to be assigned to it.

So much for the *theoretical* part of the subject; then for the *practical*. Here you must again take care to understand fully the technical terms of machinists, engineers, and constructors in every department.



In lecturing on clockwork, which I did once at Gresham College for a series of about a dozen lectures, I had among my audience some most intelligent workmen from Clerkenwell; one of these friends of mine, who wrote to me about some models of escapements, added in a P.S., "I trust you will not think me in the smallest degree disrespectful in remarking on the peculiar value most mechanics in the clock and watch trades attach to the terms for and names of things forming the parts of a clock or watch." I have no doubt I had made some blunders in the use of these technical terms, and so he goes on to tell me of the book best known in the trade.

Never neglect the opportunity of seeing works which are being carried on in your neighbourhood. Watch workmen, whenever you have the opportunity, so as to be able to account for any method you see generally adopted. Visit manufactories, try to make out the action of every part of an engine, a machine; observe the forms of tools, ask yourselves why such a form is advantageous, examine the mechanical action of each. In all hand tools there is much information to be gained in this way. The same is true of all common mechanical contrivances; the fastening of a window, a common lock, the way in which the end of its bolt is made, the roller blind, the hinges of a door, the cranks of bell wires, are all at hand to be carefully studied, and affording examples of the application of mechanical principles, very often of a refined kind, of which those who daily use them do not think.

It will be by your skill in pointing out how your knowledge of mechanics enables you to see the use of every part, that you will gain the confidence of those who wish to learn from you what these principles are.

But now I return to the point which is, as I have said, our main object.

Supposing you have gained your science certificate,—by having satisfied the examiners here that you are competent to teach a science class,—how should you set about the work?

Several questions suggest themselves.

Are you to require your class to learn geometry and algebra?

Are you to require of them some practical skill in drawing?

A man comes to you and proposes that you should give him some instruction in *mechanics*, how would you begin with him?

We will first discuss these three questions; and perhaps when we have done this we shall have made some progress in the matter upon which we have met to confer.

Are you to require your class to learn geometry and algebra?

Most distinctly and decidedly, *yes*.

You must insist on the truth that there is no solid progress to be made without it; no knowledge can be depended on unless it is founded on conviction.

An acquaintance with *results* only, without a thorough knowledge of the way in which they are attained, is a very shallow one, and not useful in the way in which it ought to be mainly useful. Many men who are employed all their lives in the mechanical arts, who are intelligent and thoughtful, see what they imagine would be improvements. The machines which they use, and which they can put into order when any part goes wrong, become familiar to them in every part, and they think this part could be altered, or that part might be removed—and, no doubt, frequently they are right; and many ingenious improvements originate in the busy and shrewd brains of the mechanic and artisan. But often too they are wrong. Consequences follow from their proposed alterations which they had not foreseen. Before the machine has come under their control it



has been the subject of many days and nights of anxious thought on the part of the designer and machine maker, and he has had objects in view which they may have missed, so that they want to be sure of the soundness of their conclusions, to be well acquainted with principles; not only RESULTS, but the principles out of which these results have been drawn, ought to be known. A man to be sure of his object must be able to reason, to calculate, to foresee.

"Invention is the talent of rapidly calling before us the many possibilities, and selecting the appropriate one."

An inventor must be able to tell what are possibilities, so as to bring his ideas to a rigid examination, and have the courage, if they do not stand the test, to discard them. All this requires a full and clear comprehension, an exact mode of reasoning, a determination to take nothing for granted for which a clear distinct reason cannot be assigned.

So, I say, a man who intends to learn mechanics to any real purpose must know how to treat mechanical problems, and he cannot do this without geometry and algebra. And if your science class is to be a successful one, you ought to make its members first of all acquire a knowledge of the elementary pure sciences. As to the way in which this is to be done I will say a few words presently. If you cannot do this your teaching will take the form of an entertaining useful lecture; certainly, you will not be entirely wasting time in showing them results, talking of what has been done, and explaining in general terms the laws on which observed phenomena rest; but this will be a sort of entertaining scientific lecture only. You will not be teaching a science class. Your evenings will have been spent in a rational and pleasant way; and your listeners will, I dare say, be gratified; but they have not, I repeat, been *taught* as a science class should be *taught*, and you will have been rather treading in the steps of the popular lecturer than realizing the object which is in view here—which I take to be, to provide for intelligent artisans and mechanics and others who are interested in their work, the means of gaining solid, accurate principles, of learning science in its true, genuine, and regular form.

Supposing that you have persuaded a man to set about acquiring the necessary knowledge of geometry, I should advise you to proceed in this way: remember he does not want to be made to *learn* propositions. He is not to be prepared for examination. There is no need to compel him to go through the process you would apply to a pupil-teacher. You must familiarize him with modes of geometrical reasoning, *show* him the graphic methods of which the elements treat. He is to be made a master of the *language*, and the *facts* of the elements.

Make him go over the propositions with you, so as to convince his judgment.

Illustrate the propositions by easy mechanical instances. Show him at every step how easy problems are solved by means of an ascertained principle.

*E.g.*, the proposition "on the same base, and on the same side of it, there cannot be two triangles, which have their sides, which are terminated in one of the extremity of the base equal to one another, and likewise their sides, which are terminated in the other extremity."

At first he will think this *jargon* merely. It always seems so to every learner; never mind that. Explain it to him; make him master the *thing itself*, and then show him how the words are chosen to give an *exact* enunciation.

Having done this, which will perhaps be a troublesome task, you can show him how it is the enunciation of a practical truth.

A five-barred gate, composed of parallelograms, has a tendency to rack at the joints, and sag down; how do you prevent it? Put the diagonal brace across, so that the parallelogrammic spaces are turned into triangles, and *racking* is impossible, *because*, so long as the sides are unaltered in length there can be but ONE triangle. Thus a *rigid* framework is constructed, by a simple process, out of one which can rack; and we KNOW that the process is effectual, because we can prove that there is but *one* triangle which has, &c. &c.

Whereas four-sided figures can rack at the angles, as every school boy knows, from his slate frame.

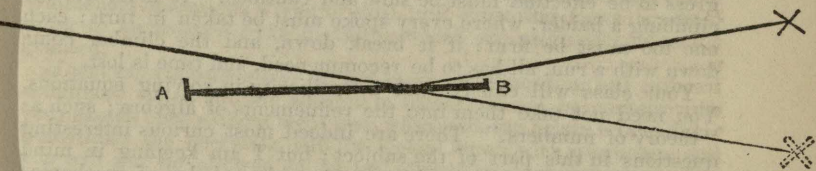
I will venture to say, that if you use such an illustration skilfully, you will have induced your friend to lay aside some of his aversion to mere abstractions. He will begin to think, "There is something in this," and be ready to go on.


Again, if you show him such a problem as this,—

Given two points on one side of a given straight line; find a point in the given line, from which lines drawn to the given points make equal angles with the given straight line.

The geometrical construction being made he will probably be pleased with the ingenious manner in which the required point is found.

Then show him that this is the problem of reflection at a plane mirror. Illustrate the geometrical truth, by showing him that in consequence of it he can see things in a mirror which are not directly before it.



Thus, explain to him how it is E can see  the image of X,

though X is not (speaking popularly) in front of the mirror, and depend upon it you will have roused the man's inquisitive faculty, if he is worth taking any trouble about, and he will go on to gain more of this kind of information; he will have been convinced that he is *gaining ideas*, and *ideas* not remote from practical facts. The battle is now won.

Read on with him geometry in this manner. The illustrations are endless. Where there are such curious facts as the 47th proposition of the first book shows him the truth by cutting out the figure, and superposing the parts.

Illustrate it by numbers.

Draw a right-angled triangle, make him measure the sides, and show him numerically that the proposition is true.

In the second book the same method will apply. Here too you are getting on the ground of mensuration; and so I might go on showing you how you should entice the learner on the threshold of science with cunning baits, letting him see as often as you can that, in what might be imagined a dreary path, there are flowers to be gathered at every step; and the ascent, though it requires an effort, is one which brings with it the reward of an ever increasing and brightening prospect.



Just in the same way in algebra. As soon as you can arrive at the solution of a simple equation, begin to illustrate it by showing him how problems are solved, and without wearying him too much with equations which are not connected with practical questions, try to make him familiar with the methods of solution, by examples which are the expressions of questions he can understand. Do them for him first of all; then make him try to repeat the same thing by himself; if he fails, help him again, and then let him again try by himself.

You will be amply rewarded by the pleasure the intelligent student will exhibit when he has succeeded for the first time in solving a question quite alone. He will feel that he has gained a new power, and will be eager to make further progress.

Here, however, I must warn you, you will find a difficulty; and one which it will demand great skill on your part to meet. This extreme desire to go on rapidly is a great difficulty; you must not too readily listen to it. The ground must be made sure at every step; as soon as it begins to be shaky and doubtful, all that comes after will partake of its weakness, and if you listen to this eager desire for pushing on too rapidly, the attainments of your class will become superficial, and untrustworthy.

You must try to make the student dwell on the parts that require practice and familiarity, by supplying him with interesting questions which attract his attention and stimulate his curiosity, while at the same time you take care that the work required in solving them is not far in advance of that with which he is familiar already. Progress to be effectual must be slow and cautious. It must be like climbing a ladder, where every spoke must be taken in turn; each one too must be firm: if it break down, and the climber come down with a run, all has to be recommenced, and time is lost.

Your class will chiefly want a familiarity in solving equations. You need not take them into the refinements of algebra; such as "theory of numbers." There are indeed most curious interesting questions in this part of the subject; but I am keeping in mind that we are ultimately to arrive at a sound knowledge of mechanics and dynamics, and therefore would, for this object, lay aside all that does not directly bear on that practical and definite end.

I shall not say much on the subject of drawing. I am quite certain that a power at least, of sketching fairly ought to be insisted on. Mechanical and engineering drawing, if it can be had, is a great help. Recollect that the men you may have in your classes may be skilled workmen, accustomed to see office drawings; they ought to be acquainted with the methods of projection. These methods are essential to their ordinary work. They have already, perhaps, some geometrical rule of thumb methods of their own. Let them be urged to be adepts in this drawing.

It will help very considerably their comprehensions to know that diagrams are according to scale. Do not draw figures carelessly; do not even presume too much on the conventional method of drawing. In teaching mathematics to those who are merely intending to have their reasoning powers strengthened, sometimes we draw a figure in a rough way, and say let it be granted that *this* is a circle, or that a line bisects an angle in a figure when it evidently does not; and this for the sake of teaching the mind to rely on the *hypothesis*, and not trust too much to the drawing. I say this is useful at times, but certainly not for beginners; the difficulty of following a logical deduction is much increased by it, and it should only be tolerated when there is already some power of following out abstractions, and for the object of increasing that power.



But you will find that it will not do with such men as you will have to teach. They have been accustomed to deal with real things. The drawings they have handled are real representations. They have been accustomed to take measurements from these drawings. Therefore I should advise you in your science class to be very careful about your drawings. Have them prepared beforehand, if they require time, or if they can be done before the learner, be very particular in making them as accurate as possible.

If you can sketch rapidly and accurately, this will be a great advantage. If you cannot, use your compass and ruler. A man who has been accustomed to accurate drawing will be repelled by any slovenliness; he will at once think you do not know much about it.

I think both master and pupil should have a good practical power of sketching accurately, and to *scale*.

Here again, I must mention another point of very great importance.

*Measurement.* It requires a great deal of practice and much care to measure accurately. I recollect that in teaching some youngsters once a little surveying, I wished to convince them of this difficulty, of measuring accurately with the chain, and so made several measure in succession the same distance, without communicating their results to each other.

When they came to compare their results, they were astonished to find what discrepancies there were; and it at once made each one eager to justify his own measure, and on trying again, every one had got a different result to what he had before, though of course they agreed more nearly.

Take this as a practical instance of how you may make one of the commonest operations a trial of skill, and show that there is something to be learned even in things which are ordinarily taken for granted.

If you are visiting works of any kind, or examining any piece of machinery which you are allowed to sketch, do not be content with your sketch only without measures, which you can figure on the lines. Sometimes the operation will be looked upon with suspicion, and you will not be allowed to be too minute in your inspection; but whenever you can, *sketch and measure*: I say it again, whenever you can, *sketch and measure*. It does me good, whenever I have been showing any piece of mechanism, or examining a curious combination, to see the scale or the foot rule appear out of the side pocket, and applied to different parts of the object under review. "This fellow knows what he is about," think I.

Now suppose you have got through your geometry and algebra, and your class are prepared to follow you, whenever you have occasion to refer to these elements, and that they can sketch accurately, and to *scale*.

We begin *Mechanics*.

I have already said that *principles* are most important; and in passing to reasonings which require conceptions and principles drawn from the material world, it is more difficult to attain exactness of logic and precision of form. Hard as it is, it must be aimed at. Nothing is to be left arbitrary or precarious.

You come at once to definitions of *force* and its *measures*—the most intelligible of all measures of force, used statically, is *weight*. The third law of motion connects *inertia* with *weight*. This then gives us a large subject on which clear notions must be obtained; *weight* must be fully explained; and the effect of force will always be represented by supposing some *weight* sustained by it. Then you get the notion of *pressure*.



the force exerted by a solid body; *compression*, the result of pressure on solid bodies; *tension*, the result of stretching pressures on cords.

Do not grudge taking a very considerable time in fixing these ideas; they are so essential that without an accurate and complete notion of them, what is done in mechanics is nothing but a motley medley.

As you will have to talk of *rigid* bodies to men who know very well that the substances they have to deal with are *flexible* and *frangible*, you will have to explain carefully why we were obliged to imagine such non-existent qualities as *rigid* and *perfectly elastic*, in order that certain conclusions being established with respect to these abnormal states, we may have the more safe ground when we treat of bodies as they really are—flexible, frangible, imperfectly elastic—pointing out in each case how the new condition introduced is first of all to be measured, and then how it will influence previous results.

"Hypotheses," says Dr. Whewell in his Aphorisms concerning Science, "may be useful though involving much that is superfluous, and even erroneous; for they may supply the true bond of connexion of facts; and the superfluity and error may afterwards be pared away."

This is the case in mechanics, where we begin by investigating the conditions of equilibrium of bodies perfectly rigid.

I should advise you not to give an abstract analytical proof of such a proportion as the parallelogram of forces, *at first*. Make your pupils familiar with it, as in Whewell's "Elem. Mechanics" from the Properties of the Lever, first of all; and use the mechanical apparatus, such as that of which we have a specimen in the museum, to exhibit its truth. Afterwards, if the class can grasp it, give them the abstract demonstration. But for our present object I should not so much care about this.

I think you will, by the method of *mechanism*, succeed better in fixing mechanical ideas than you will if you keep too much to the systematic treatises.

You can consult, for example, such books as Baker's "Elements of Mechanism," or Tate's "Elements of Mechanism," which in size and price are in everyone's reach. These books will be constantly supplying you with examples of the combination of the simpler mechanical powers, which you should dissect and illustrate by numerical suppositions. These you will also find assisted by such books as Tate's "*Exercises on Mechanics*," and Canon Moseley's "*Mechanics applied to the Arts*."

I shall say nothing about using the principle of "*work*;" it is well to know it and be able to use it, but I quite disapprove of making it the only method. I think those who have done so, have worked their hobby too much, and have not promoted a sound knowledge of mechanics founded on logical geometrical deductions.

Another stage of your class teaching, requiring very great care and caution, is when you have to treat of *accelerating force*.

I have always found that a smatterer is most easily detected when you get him to talk of *velocity*, *momentum*, *accelerating*, and *moving force*.

Never allow any of these terms to be used in a loose sense; we may say of them as *Linnaeus* said of terms in Botany,

"*Nomina si nescis, perit et cognitio rerum.*"

If you do not thoroughly know the terms, the knowledge of the things themselves perishes.

In hydrostatics, I advise that you make all depend on *one principle*,—the equality of fluid pressure,—do not make a number of physical facts each into a *principle*, as is done in some books.

You want your classes to have a scientific knowledge of principles, and what may be deduced from them. You will smother up all real knowledge if you overload every part with imaginary first principles, each of which is in fact dependent on *one main property*, which explains all.

I will just illustrate by an anecdote the importance of this fundamental principle of Hydrostatics, and then leave you to gather what you may from the few hints I have thrown out for your guidance this evening.

A person once came to me when I was the director of the Engineering College at Putney, with an invention which he wished me to look at; it was a machine to procure power by means of fluid pressure, a hydrostatical power engine. He explained his notions to me, exhibiting in diagrams a formidable series of pumps, &c., which were in fact to manufacture *power*. I demurred to the notion on first principles; because, as machines only *modify*, and do not *create* power, this was sufficient for me to come to a conclusion that there was a misapprehension somewhere, and that my visitor was mistaken.

At his urgent request, however, I went over the details, and was soon able to show him that he had assumed *action* from pressure without reckoning on *reaction*, and that the machine would not work at all. He ignored the law of the equality of fluid pressure.

Of course he was not convinced, but left me; and some time after, had evidently found a dupe. A person was willing to advance money on the invention if he could procure a certificate of its being founded on correct principles; and he actually had the audacity to offer me 1,000*l.* if I would certify to the soundness of his views.

I adopted the mildest course under the circumstances in ringing the bell, and desiring him to leave my room, and I trust he did not find anyone unprincipled enough to help him in the way he proposed. But here was a person ignoring the elementary principles of science, who had found a capitalist to help him in his absurd scheme.

Such things ought to be impossible. Inventions which ignore the fundamental truths of science ought to find no patrons and no *parents*.

Sometimes they are not conceived in fraud but in ignorance. Our intelligent mechanics and artisans sometimes waste their own and their friends' money in taking out patents for inventions which are impossible, and if by the growth of our scientific classes we can teach these men better, we shall probably find that their ingenuity is more successfully exerted, with greater advantage to themselves and to the country at large; and a debt of gratitude will be incurred by us all towards those skilled teachers in science schools who will have been the means of diffusing sound, accurate, and clear scientific knowledge amongst our clever hard-headed workmen, a class which is one of the main sinews of the Commonwealth.





Box 7  
Science and Art Department of the Committee of  
Council on Education.

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## LECTURES

ADDRESSED TO TEACHERS

ON

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE

METHOD OF TEACHING A SCIENCE CLASS.

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### LECTURE III.

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ON EXPERIMENTAL PHYSICS,

DELIVERED AT

THE SOUTH KENSINGTON MUSEUM,

30th April 1861,

BY

PROFESSOR TYNDALL, F.R.S.



LONDON:

PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,  
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.

1861.

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*Price Twopence.*



LECTURES AND THE INFLUENCE OF THE SCIENCE OF  
PHYSICS ON THE SCIENCE OF CHEMISTRY

LECTURES

ADDRESSED TO TEACHERS

PREPARATION FOR OBTAINING DEGREE  
OF BACHELOR OF SCIENCE

METHOD OF TEACHING A SCIENCE (1914)

LECTURE III.

ON EXPERIMENTAL PHYSICS

THE SCIENCE OF PHYSICS

1914

PROFESSOR OF PHYSICS

PRINTED BY GEORGE ALLEN AND UNWIN LTD. LONDON  
1914

1914

## LECTURE.

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WE have no reason to believe that the sheep or the dog, or indeed any of the lower animals, feel an interest in the laws by which natural phenomena are regulated. A herd may be terrified by a thunder-storm; birds may go to roost, and cattle return to their stalls during a solar eclipse; but neither birds nor cattle, as far as we know, ever think of inquiring into the causes of these things. It is otherwise with man. The presence of natural objects, the occurrence of natural events, the varied appearances of the universe in which he dwells, penetrate beyond his organs of sense, and appeal to an inner power of which the senses are the mere instruments and excitants. No fact is to him either final or original. He cannot limit himself to the contemplation of it alone, but endeavours to ascertain its position in a series to which the constitution of his mind assures him it must belong. He regards all that he witnesses in the present as the efflux and sequence of something that has gone before, and as the source of a system of events which is to follow. The notion of spontaneity, by which in his ruder state he accounted for natural events, is abandoned; the idea that nature is an aggregate of independent parts also disappears, as the connexion and mutual dependence of physical powers become more and more manifest: until he is finally led, and that chiefly by the science of which I happen this evening to be the exponent, to regard Nature as an organic whole, as a body each of whose members sympathizes with the rest, changing, it is true, from ages to ages, but without one real break of continuity, or a single interruption of the fixed relations of cause and effect.

The system of things which we call Nature is, however, too vast and various to be studied first-hand by any single mind. As knowledge extends there is always a tendency to subdivide the field of investigation, its various parts being taken up by different individuals, and thus receiving a greater amount of attention than could possibly be bestowed on them if each investigator aimed at the mastery of the whole. East, west, north, and south, the human mind pushes its conquests; but the centripetal form in which knowledge, as a whole, advances, spreading ever wider on all sides, is due in reality to the exertions of individuals, each of whom directs his efforts, more or less, along a single line. Accepting, in many respects, his culture from his fellow men, taking it from spoken words and from written books, in some one direction, the student of nature must actually touch his work. He may otherwise be a distributor of knowledge, but not a creator, and fails to attain that vitality of thought and correctness of judgment which direct and habitual contact with natural truth can alone impart.

One large department of the system of nature which forms the chief subject of my own studies, and to which it is my duty to call your attention this evening, is that of physics or natural philosophy. This term is large enough to cover the study of nature generally, but it is usually restricted to a department which, perhaps, lies closer to our perceptions than any other. It deals with the phenomena and laws of light and heat—with the phenomena and laws of magnetism and electricity—with those of sound—with the pressures



and motions of liquids and gases, whether in a state of translation or of undulation. The science of mechanics is a portion of natural philosophy, though at present so large as to need the exclusive attention of him who would cultivate it profoundly. Astronomy is the application of physics to the motions of the heavenly bodies, the vastness of the field causing it, however, to be regarded as a department in itself. In chemistry physical agents play important parts. By heat we cause bodies to combine, and by heat we decompose them. Electricity tears asunder the locked atoms of compounds; the solar beams build up the whole vegetable world, and by it the animal, in virtue of their power of separating carbonic acid into its constituents; while the touch of the self same beams causes hydrogen and chlorine to unite with sudden explosion and form by their combination a powerful acid. Thus physics and chemistry intermingle, physical agents being made use of by the chemist as a means to an end; while in physics proper the laws and phenomena of the agents themselves, both qualitative and quantitative, are the primary objects of attention.

Well, my duty here to night is to spend an hour in telling how this subject is to be studied, and how a knowledge of it is to be imparted to others. When I was first invited to do this, I hesitated before accepting the responsibility. I might readily entertain you with an account of what natural philosophy has accomplished, I might point to those applications of science regarding which we hear so much in the newspapers, and which we often see mistaken for science itself. I might, of course, ring changes on the steam engine and the telegraph, the electrotype and the photograph, the medical applications of physics, and the million other inlets by which scientific thought filters into practical life. That would be easy compared with the task of informing you how you are to make the study of physics the instrument of your own mental culture, how you are to possess its facts and make those facts living seeds which shall take root and blossom in the mind, and not lie like dead lumber in the storehouse of memory. This is a task much heavier than the mere cataloguing of scientific achievements; and it is one which, feeling my own want of time and power to execute it aright, I might well hesitate to accept.

But let me sink excuses, and attack the work as best I may. First and foremost, then, I would advise you to get a knowledge of facts from actual observation. Facts looked at directly are vital; when they pass into words half the sap is taken out of them. You wish, for example, to get a knowledge of magnetism; well, provide yourself with a good book on the subject, if you can, but do not be content with what the book tells you; do not be satisfied with its descriptive woodcuts; see the actual thing yourself. Half of our book writers describe experiments which they never made, and their descriptions often lack both force and truth; but no matter how clever or conscientious they may be, their written words cannot supply the place of actual observation. Every fact has numerous radiations, which are shorn off by the man who describes it. Go, then, to a philosophical instrument maker, and give, according to your means, for a straight bar-magnet, say, half-a-crown, or five shillings for a pair of them, if you can afford it; or get a smith to cut a length of ten inches from a bar of steel an inch wide and half an inch thick; file its ends decently, harden it, and get somebody like myself to magnetize it. Two bar-magnets are better than one. Procure some darning needles; here, you see, I have such. Provide yourself also with a little unspun silk; this will give you a suspending fibre void of torsion; make a little loop of paper or of

wire, thus, and attach your fibre to it. Do it neatly. In the loop place your darning needle, and bring the two ends or poles, as they are called, of your magnet successively up to either end of the needle. Both the poles, you find, attract both ends of the needle. Replace the needle by a bit of annealed iron wire, the same effects ensue. Suspend successively little rods of lead, copper, silver, or brass, of wood, glass, ivory, or whalebone; the magnet produces no sensible effect upon any of these substances. You thence infer a special property in the case of steel and iron. Multiply your experiments, however, and you will find that some other substances besides iron are acted upon by your magnet. A rod of the metal nickel, or of the metal cobalt from which the blue colour used by painters is derived, exhibits powers similar to those observed with the iron and steel.

In studying the character of the force you may, however, confine yourself to iron and steel, which are always at hand. Make your experiments with the darning needle over and over again; operate on both ends of the needle; try both ends of the magnet. Do not think the work stupid; you are conversing with Nature, and must acquire a certain grace and mastery over her language; and these practice can alone impart. Let every movement be made with care, and avoid slovenliness from the outset. In every one of your experiments endeavour to feel the responsibility of a moral agent. Experiment, as I have said, is the language by which we address Nature, and through which she sends her replies; and in the use of this language a lack of straightforwardness is as possible and prejudicial as in the spoken language of the tongue. If you wish to become acquainted with the truth of Nature you must from the first resolve to deal with her sincerely.

Now remove your needle from its loop, and draw it from end to end along one of the ends of the magnet; resuspend it, and repeat your former experiment. You find the result different. You now find that each extremity of the magnet attracts one end of the needle, and repels the other. The simple attraction observed in the first instance is now replaced by a *dual* force. Repeat the experiment till you have thoroughly observed the ends which attract and those which repel each other.

Withdraw the magnet entirely from the vicinity of your needle, and leave the latter freely suspended by its fibre. Shelter it as well as you can from currents of air, and if you have iron buttons on your coat or a steel penknife in your pocket, beware of their action. If you work at night, beware of iron candlesticks, or of brass ones with iron rods inside. Freed from such disturbances, the needle takes up a certain determinate position. It sets its length nearly north and south. Draw it aside from this position and let it go. After several oscillations it will again come to it. If you have obtained your magnet from a philosophical instrument maker, you will see a mark on one of its ends. Supposing, then, that you drew your needle along the end thus marked, and that the eye-end of your needle was the last to quit the magnet, you will find that the eye turns to the south, the point of the needle turning towards the north. Make sure of this, and do not take this statement on my authority.

Now take a second darning needle like the first, and magnetize it in precisely the same manner: freely suspended it also will turn its point to the north and its eye to the south. Your next step is to examine the action of the two needles which you have thus magnetized upon each other.

Take one of them in your hand, and leave the other suspended; bring the eye end of the former near the eye end of the latter; the



suspended needle retreats : it is repelled. Make the same experiment with the two points, you obtain the same result, the suspended needle is repelled. Now cause the dissimilar ends to act on each other—you have attraction—point attracts eye and eye attracts point. Prove the reciprocity of this action by removing the suspended needle, and putting the other in its place. You obtain the same result. The attraction, then, is mutual, and the repulsion is mutual, and you have thus demonstrated in the clearest manner the fundamental law of magnetism, that like poles, as the ends are termed, repel, and unlike poles attract each other. You may say that this is all easily understood without doing ; but *do it*, and your knowledge will not be confined to what I have uttered here.

I have said that one end of your magnet has a mark upon it ; lay several silk fibres together, so as to get sufficient strength, and form a loop large enough to hold your magnet. Suspend it ; it turns its marked end towards the north. This marked end is that which in England is called the north pole. If the smith has made your magnet it will be convenient to determine its north pole yourself, and to mark it with a file. You vary your experiments by causing your magnetized darning needle to attract and repel your large magnet : it is quite competent to do so. In magnetizing the needle, I have supposed the eye to be the last to quit the marked end of the magnet ; that end of the needle is a south pole. The end which last quits the magnet is always opposed in polarity to the end of the magnet with which it has been in contact. Brought near each other they mutually attract, and thus demonstrate that they are unlike poles.

You may perhaps learn all this in a single hour ; but spend several at it, if necessary ; and remember understanding it is not sufficient : you must obtain a manual aptitude in addressing Nature. If you speak to your fellow man you are not entitled to use jargon. Bad experiments are jargon addressed to Nature, and just as much to be deprecated. A manual dexterity in illustrating the interaction of magnetic poles is of the utmost importance at this stage of your progress ; and you must not neglect attaining this power over your implements. As you proceed, moreover, you will be tempted to do more than I can possibly suggest. Thoughts will occur to you which you will endeavour to follow out ; questions will arise which you will try to answer. The same experiment may be twenty things to twenty people. Having witnessed the action of pole on pole through the air, you will perhaps try whether the magnetic power is not to be screened off. You use plates of glass, wood, slate, pasteboard, or gutta-percha, but find them all pervious to this wondrous force. One pole acts upon another through these bodies sensibly, as if they were not present. And should you become a patentee for the regulation of ships' compasses, you will not fall, as some have done, into the stupid error of screening off the magnetism of the ship by the interposition of such substances.

If you wish to teach a class you must contrive that the effects which you have thus far witnessed for yourself shall be witnessed by 20 or 30 pupils. And here your private ingenuity must come into play. You will attach bits of paper to your needles, so as to render their movements visible at a distance, denoting the north and south poles by different colours, say green and red. You may also improve upon your darning needle. Take a strip of sheet steel, the rib of a lady's stays will answer, heat it to vivid redness and plunge it into cold water. It is thereby hardened, rendered, in fact, almost as brittle as glass. Six inches of this, magnetized in the manner of the darning needle, will in all probability be better able to carry

your paper indexes. Having secured such a strip, you proceed thus :—

Magnetize a small sewing needle and determine its poles; or, break half an inch or an inch off your magnetized darning needle and suspend it by a fine silk fibre. The sewing needle or the fragment of the darning needle is now to be used as a test needle to examine the distribution of the magnetism in your strip of steel. Hold the strip upright in your left hand, and cause the test needle to approach the lower end of your strip; one end is attracted, the other is repelled. Raise your needle along the strip; its oscillations, which at first were quick, become slower; opposite the middle of the strip they cease entirely; neither end of the needle is attracted; above the middle the test needle turns suddenly round, its other end being now attracted. Go through the experiment thoroughly; you thus learn that the entire lower half of the strip attracts one end of the needle, while the entire upper half attracts the opposite end. Supposing the north end of your little needle to be that attracted below, you infer that the entire lower half of your magnetized strip exhibits south polarity, while the entire upper half exhibits north polarity. So far, then, you have determined the distribution of magnetism in your strip of steel.

You look at this fact, you think of it; in its suggestiveness the value of the experiment chiefly consists. The thought arises, "What will occur if I break my strip of steel across in the middle? Shall I obtain two magnets each possessing a single pole?" Try the experiment; break your strip of steel, and test each half as you tested the whole. The mere presentation of its two ends in succession to your test needle suffices to show you that you have *not* a magnet with a single pole, that each half possesses two poles, and a neutral point between them. And if you again break the half into two other halves, you will find that each quarter of the original strip exhibits precisely the same magnetic distribution as the strip itself. You may continue the breaking process; no matter how small your fragment may be, it still possesses two opposite poles and a neutral point between them. Well, your hand ceases to break where breaking becomes a mechanical impossibility; but does the mind stop there? No: you follow the breaking process in idea when you can no longer realize it in fact; your thoughts wander amid the very atoms of your steel, and you conclude that each atom is a magnet, and that the force exerted by the strip of steel is the mere summation or resultant of the forces of its ultimate particles.

Here, then, is an exhibition of power which we can call forth or cause to disappear at pleasure. We magnetize our strip of steel by drawing it along the pole of a magnet; we can demagnetize it, or reverse its magnetism, by properly drawing it along the same pole in the opposite direction. What, then, is the real nature of this wondrous change? What is it that takes place among the atoms of the steel when the substance is magnetized? The question leads us beyond the region of sense, and into that of imagination. This latter faculty is indeed the divining rod of the man of science. Not an imagination merely which exercises itself in vague fancies, but one capable of seizing firmly on a consistent physical image as a principle, of deducing consequences from it, and of devising means whereby these deductions may be brought to the touchstone of experiment. If such a principle be adequate to render a satisfactory account of all the phenomena, if from an assumed cause the observed facts necessarily follow, we call the assumption a theory, and once possessing it, we can not only revive at pleasure the facts which we have observed, but we can predict those which we have



never seen. Thus, then, in the prosecution of physical science, our powers of observation, memory, imagination, and inference all are drawn upon. We see the fact and store it up; imagination broods upon these memories, the theory flashes on the mind, and then the deductive faculty interposes to carry out the principle to its logical results. A perfect theory gives to the human mind dominion over natural phenomena; but even an assumption which can only partially stand the test of a comparison with facts, may be of eminent use in enabling us to connect and classify groups of phenomena. The theory of magnetic fluids is of this latter character, and with it we must now make ourselves familiar.

With the view of stamping the thing more firmly on your minds, I will make use of a strong and vivid image. In optics, red and green are called complementary colours; their mixture produces *white*. Now I ask you to imagine each of these colours to possess a self-repulsive power; that red repels red, and that green repels green; but that red attracts green and green attracts red, the attraction of the dissimilar colours being equal to the repulsion of the similar ones. Imagine the two colours mixed so as to produce white, and suppose two strips of wood painted with this white; what will be their action upon each other? Suspend one of them freely as we suspended our darning needle, and bring the other near it; what will occur? True, the red component of the strip you hold in your hand will repel the red component of your suspended strip, but then it will attract the green; and the forces being equal they neutralize each other. In fact, the least reflection shows you that the strips will be as indifferent to each other as two unmagnetized darning needles would be under the same circumstances.

But suppose, instead of mixing the colours, we painted one half of each strip from centre to end red, and the other half green, it is perfectly manifest that the two strips would now behave towards each other exactly as our two magnetized darning needles—the red end would repel the red and attract the green, the green would repel the green and attract the red; so that, assuming two paints thus related to each other, we could by their mixture produce the neutrality of an unmagnetized body, while by their separation we could produce a duality of action similar to that of magnetized bodies.

I doubt not you have already anticipated a defect in my conception; for if we break one of our strips of wood in the middle we have one half entirely red and the other entirely green, and with these it would be impossible to imitate the action of our broken magnet. How then must we modify our conception? We must evidently suppose *each atom of the wood* painted green on one face and red on the opposite one. If this were done the resultant action of all the atoms would exactly resemble the action of a magnet. Here also, if the two opposite colours of each atom could be caused to mix so as to produce white, we should have, as before, perfect neutrality.

Substitute in your minds for these two self-repellent and mutually attractive colours two invisible self-repellent and mutually attractive fluids, which in ordinary steel are mixed to form a neutral compound, but which the act of magnetization separates from each other, placing the opposite fluids on the opposite faces of each atom, and you have a perfectly distinct conception of the celebrated theory of magnetic fluids. The strength of the magnetism excited is supposed to be proportional to the quantity of neutral fluid decomposed. According to this theory nothing is actually transferred from the exciting magnet to the excited steel. The act of magnetization consists in the forcible separation of two powers which existed in the steel before it was magnetized, but which then neutralized each

other by their coalescence. And if you test your magnet after it has excited a hundred pieces of steel, you will find that it has lost no force—no more, indeed, than I should lose had my words such a magnetic influence on your minds, as to excite in them a strong resolve to study natural philosophy. I should, in fact, be the gainer by my own utterance and by the reaction of your strength; and so also the magnet is the gainer by the reaction of the body which it magnetizes.

Look now, to your excited piece of steel; figure each atom to your minds with its opposed fluids spread over its opposite faces. How can this state of things be permanent? The fluids, by hypothesis, attract each other; what, then, keeps them apart? Why do they not instantly rush together across the equator of the atom, and thus neutralize each other? To meet this question philosophers have been obliged to infer the existence of a special force which holds the fluids asunder. They call it *coercive force*; and it is found that those kinds of steel which offer most resistance to being magnetized, which require the greatest amount of coercion to tear their fluids asunder, are the very ones which offer the greatest resistance to the re-union of the fluids after they have been once separated. Such kinds of steel are most suited to the formation of *permanent* magnets. It is manifest, indeed, that without coercive force a permanent magnet would not be at all possible.

You have not forgotten that previous to magnetizing your darning needle *both* its ends were attracted by your magnet; and that both ends of your bit of iron wire were acted upon in the same way. Probably also long before this you will have dipped the end of your magnet among iron filings, and observed how they cling to it, or into a nailbox, and found how it drags the nails after it. I know very well that if you are not the slaves of routine, you will have by this time done many things that I have not told you to do, and thus multiplied your experience beyond what I have indicated. You are almost sure to have caused a bit of iron to hang from the end of your magnet, and you have probably succeeded in causing a second piece to attach itself to the first, a third to the second; until finally the force has become too feeble to bear the weight of more. If you have operated with nails you may have observed that the points and edges hold together with the greatest tenacity; and that a bit of iron clings more firmly to the corner of your magnet than to one of its flat surfaces. In short you will in all likelihood have enriched your experience in many ways without any special direction from me.

Well, the magnet attracts the nail, and that nail attracts a second one. This proves that the nail in contact with the magnet has had the magnetic quality developed in it by that contact. If it be withdrawn from the magnet its power to attract its fellow nail ceases. Contact, however, is not necessary. A sheet of glass or paper, or a space of air may exist between the magnet and the nail; the latter is still magnetized, though not so forcibly as when in actual contact. The nail then presented to the magnet is itself a temporary magnet. That end which is turned towards the magnetic pole has the opposite magnetism of the pole which excites it; the end most remote from the pole has the same magnetism as the pole itself, and between the two poles the nail, like the magnet, possesses a magnetic equator. Conversant as you now are with the theory of magnetic fluids, you have already, I doubt not, anticipated me in imagining the exact condition of the iron under the influence of the magnet. You picture the iron as possessing the neutral fluid in abundance, you picture the magnetic pole, when brought near, de-



composing the fluid; repelling the fluid of a like kind with itself, and attracting the unlike fluid; thus exciting in the parts of the iron nearest to itself the opposite polarity. But the iron is incapable of becoming a permanent magnet. It only shows its virtue as long as the magnet acts upon it. What then does the iron lack which the steel possesses? Your reply I know is ready—it lacks coercive force. Its fluids are separated with ease, but once the separating cause is removed, they flow together again and neutrality is restored. Your imagination must be quite nimble in picturing these changes. You must be able to see the fluids dividing and reuniting according as the magnet is brought near or withdrawn. Fixing a definite pole in your imagination you must picture the precise arrangement of the two fluids with reference to this pole. And you must not only be well drilled in the use of this mental imagery yourself, but you must be able to arouse the same pictures in the minds of your pupils, and satisfy yourself that they possess this power by placing before them magnets and iron in various positions, and asking them to describe the exact magnetic state of the iron in each particular case. The mere facts of magnetism will have their interest immensely augmented by an acquaintance with those hidden principles whereon the facts depend. Still, while you use this theory of magnetic fluids to track out the phenomena and link them together, be sure to tell your pupils that it is to be regarded as a symbol merely,—a symbol, moreover, which is incompetent to cover all the facts,\* but which does good practical service whilst we are waiting for the actual truth.

This state of excitement into which the soft iron is thrown by the influence of the magnet, is sometimes called “magnetization by influence.” More commonly, however, the magnetism is said to be “induced” in the soft iron, and hence this temporary magnetism is called “magnetic induction.” Now, there is nothing theoretically perfect in nature: there is no iron so soft as not to possess a certain amount of coercive force, and no steel so hard as not to be capable, in some degree, of magnetic induction. The quality of steel is in some measure possessed by iron, and the quality of iron is shared in some degree by steel. It is in virtue of this latter fact that the unmagnetized darning needle was attracted in your first experiment; and from this you at once deduce the consequence that after the steel has been magnetized, the repulsive action of a magnet must be always less than its attractive action. For the repulsion is opposed by the inductive action of the magnet on the steel, while the attraction is assisted by the same inductive action. Make this clear to your minds, and verify it by your experiments. In some cases you can actually make the attraction due to the temporary magnetism overbalance the repulsion due to the permanent magnetism, and thus cause two poles of the same kind apparently to attract each other. When, however, good hard magnets act on each other from a sufficient distance, the inductive action practically vanishes, and the repulsion of like poles is sensibly equal to the attraction of unlike ones.

I dwell thus long on elementary principles, because they are of the first importance, and it is the temptation of our time to neglect them. Now follow me a little further. In examining the

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\* This theory breaks down when applied to diamagnetic bodies, which are repelled by magnets. Like soft iron, such bodies are thrown into a state of temporary excitement in virtue of which they are repelled, but any attempt to explain such a repulsion by the decomposition of a fluid will demonstrate its own futility.

distribution of magnetism in your strip of steel you raised the needle slowly from bottom to top, and found what we called a neutral point at the centre. Now does the magnet really exert no influence on the pole presented to its centre? Let us see.

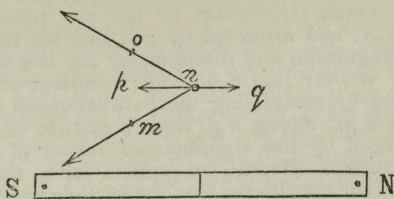


Fig. 1.

Let S N, Fig. 1, be your magnet and let  $n$  represent a particle of north magnetism placed exactly opposite the middle of the magnet. Of course this is an imaginary case, as you can never in reality thus detach your north magnetism from its neighbour. What is the action of the two poles of the magnet on  $n$ ? Your reply will of course be that S attracts  $n$  while N repels it. Let the magnitude and direction of the attraction be expressed by the line  $n m$ , and the magnitude and direction of the repulsion by the line  $n o$ . Now the particle  $n$  being equally distant from S and N, the line  $n o$ , expressing the repulsion, must be equal to  $n m$ , which expresses the attraction, and the particle  $n$ , acted upon by two such forces, must evidently move in the direction  $n p$ , exactly midway between  $n m$  and  $n o$ . Hence you see that although there is no tendency of the particle  $n$  to move towards the magnetic equator, there is a tendency on its part to move parallel to the magnet. If instead of a particle of north magnetism we placed a particle of south magnetism opposite to the magnetic equator, it would evidently be urged along the line  $n q$ ; and if instead of two separate particles of magnetism we place a little magnetic needle, containing both north and south magnetism, opposite the magnetic equator, its south pole being urged along  $n q$ , and its north along  $n p$ , the little needle will be compelled to set itself parallel to the magnet S N. Make the experiment and satisfy yourselves that this is the case.

Substitute for your magnetic needle a bit of soft iron wire, devoid of permanent magnetism, and it will set itself exactly as the needle does. Acted upon by the magnet, the wire, as you know, becomes a magnet and behaves as such; it will, of course, turn its north pole towards  $p$ , and south pole towards  $q$ , just like the needle.

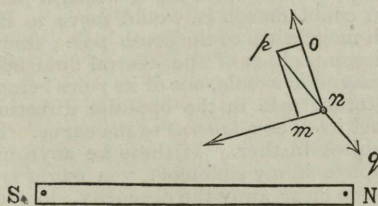


Fig.



But supposing you shift the position of your particle of north magnetism, and bring it nearer to one end of your magnet than to the other, the forces acting on the particle are no longer equal; the nearest pole of the magnet will act more powerfully on the particle than the more distant one. Let  $S\ N$ , Fig. 2, be the magnet and  $n$  the particle of north magnetism in its new position. Well, it is repelled by  $N$ , and attracted by  $S$ . Let the repulsion be represented in magnitude and direction by the line  $n\ o$ , and the attraction by the shorter line  $n\ m$ . The resultant of these two forces will be found by completing the parallelogram  $m\ o$ , and drawing its diagonal  $n\ p$ . Along  $n\ p$ , then, a particle of north magnetism would be urged by the simultaneous action of  $S$  and  $N$ . Substituting a particle of south magnetism for  $n$ , the same reasoning would lead to the conclusion that the particle would be urged along  $n\ q$ ; and if we place at  $n$  a short magnetic needle, its north pole will be urged along  $n\ p$ , and its south pole along  $n\ q$ ; and the only position possible to the needle, thus acted on, is along the line  $p\ q$ , which, as you see, is no longer parallel to the magnet. Verify this by actual experiment.

In this way we might go round the entire magnet, and considering its two poles as two centres from which the force emanates, we can, in accordance with ordinary mechanical principles, assign a definite direction to the magnetic needle at every particular place. And substituting, as before, a bit of iron wire for the magnetic needle, the positions of both will be the same.

Now, I think, without further preface, you will be able to comprehend for yourselves, and explain to others, one of the most interesting effects in the whole domain of magnetism. I have here some iron filings, particles of iron, irregular in shape, being longer in some directions than in others. Or, instead of the iron filings, I may take very small scraps of thin iron wire. Well, I place a sheet of paper over my magnet; it is all the better if the paper be stretched on a wooden frame, as this enables us to keep it quite level. I scatter my filings, or my scraps of wire from a sieve upon the paper, and tap the latter gently, so as to liberate the particles for a moment from its friction. The magnet acts on the filings through the paper, and see how it arranges them! They embrace the magnet in a series of beautiful curves, which are technically called magnetic curves, or lines of magnetic force. Does the meaning of these lines yet flash upon you? Set your magnetic needle or your suspended bit of wire at any point of one of the curves and you will find the direction of the needle or of the wire to be exactly that of the particle of iron, or of the magnetic curve at the point. Go round and round the magnet; the direction of your needle always coincides with the direction of the curve on which it is placed. These, then, are the lines along which a particle of south magnetism, if you could detach it, would move to the north pole, and a bit of north magnetism to the south pole; they are the lines along which the decomposition of the neutral fluid takes place, and in the case of the magnetic needle, one of its poles being urged in one direction, and the other pole in the opposite direction, the needle must necessarily set itself as a *tangent* to the curve. I will not seek to simplify this subject further. If there be anything obscure or confused or incomplete in my statement, you ought now, by patient thought, to be able to clear away the obscurity, to reduce the confusion to order, and to supply what is needed to render the explanation complete. Do not quit the subject until you thoroughly understand it; and if you are able to look with your mind's eye at

the play of forces around a magnet, and see distinctly the operation of those forces in the production of the magnetic curves, the time which we have spent together has not been spent in vain.

In this thorough manner we must master our materials, reason upon them, and by determined study, attain to clearness of conception. Facts thus dealt with exercise an expansive force upon the boundaries of thought;—they widen the mind to generalization. We soon recognize a brotherhood between the larger phenomena of nature, and the minute effects which we have observed in our private chambers. Why, we inquire, does the magnetic needle set north and south? Evidently it is compelled to do so by the earth; the great globe which we inherit is itself a magnet. Let us learn a little more about it. By means of a bit of wax or otherwise attach your silk fibre to your magnetic needle by a single point at its middle, the needle will thus be uninterfered with by the paper loop, and will enjoy to some extent a power of dipping its point or its eye below the horizon. Lay your magnet on a table, and hold the needle over the equator of the magnet. The needle sets horizontal. Move it towards the north end of the magnet; the south end of the needle dips, the dip augmenting as you approach the north pole. Over the latter the needle, if free to move, will set itself exactly vertical. Move it back to the centre, it reassumes its horizontality; pass it on towards the south pole, its north end now dips, and directly over the south pole the needle becomes vertical, its north end being now turned downwards. Thus we learn that on the one side of the magnetic equator the north end of the needle dips; on the other side the south end dips, the dip varying from nothing to ninety degrees. If we go to the equatorial regions of the earth with a suitably suspended needle we shall find there the position of the needle horizontal. If we sail north one end of the needle dips; if we sail south the opposite end dips; and over the north or south terrestrial magnetic pole the needle sets vertical. The south magnetic pole has not yet been found, but Sir James Ross discovered the north magnetic pole on the 1st of June 1831. In this manner we establish a complete parallelism between the action of the earth and that of an ordinary magnet. The terrestrial magnetic poles do not coincide with the geographical ones; nor does the earth's magnetic equator quite coincide with the geographical equator. The direction of the magnetic needle in London, which is called the magnetic meridian, incloses an angle of about 24 degrees with the true astronomical meridian, this angle being called the Declination of the needle for London. The north pole of the needle now lies to the west of the true meridian; or in other words the declination is westerly; but its amount varies, and in the year 1660 the declination was nothing, while before that time it was easterly. All this proves that the earth's magnetic constituents are gradually changing their distribution. This change is very slow; it is technically called the secular change, and the observation of it has not yet extended over a sufficient period of time to enable us to guess even approximately, at its laws.

Having thus discovered, to some extent, the secret of the earth's power, we can turn it to account. I hold in my hand a poker formed of good soft iron; it is now in the line of dip, a tangent, in fact, to the earth's line of magnetic force. The earth, acting as a magnet, is at this moment constraining the two fluids of the poker to separate, making the lower end of the poker a north pole, and the upper end a south pole. Mark the experiment:—I hold the knob uppermost, and it attracts the north end of a magnetic needle. I now reverse the poker, bringing its knob undermost; the knob is now



a north pole and attracts the south end of a magnetic needle. Get such a poker and carefully repeat this experiment; satisfy yourselves that the fluids shift their position according to the manner in which the poker is presented to the earth. It has already been stated that the softest iron possesses a certain amount of coercive force. The earth, at this moment, finds in this force an antagonist which opposes the full decomposition of the neutral fluid. The component fluids may be figured as meeting an amount of friction, or possessing an amount of adhesion, which prevents them from gliding over the atoms of the poker. Can we assist the earth in this case? If we wish to remove the residue of a powder from the interior surface of a glass to which the powder clings, we invert the glass, tap it, loosen the hold of the powder, and thus enable the force of gravity to pull it down. So also by tapping the end of the poker we loosen the adhesion of the fluids to the atoms and enable the earth to pull them apart. But, what is the consequence? The portion of fluid which has been thus forcibly dragged over the atoms refuses to return when the poker has been removed from the line of dip; the iron, as you see, has become a permanent magnet. By reversing its position and tapping it again we reverse its magnetism. A thoughtful and competent teacher will well know how to place these remarkable facts before his pupils in a manner which will excite their interest; he will know, and if not, will try to learn, how by the use of sensible images, more or less gross, to give those he teaches definite conceptions, purifying these conceptions more and more as the minds of his pupils become more capable of abstraction. He will cause his logic to run like a line of light through these images, and by thus acting he will cause his boys to march at his side with a profit and a joy, which the mere exhibition of facts without principles, or the appeal to the bodily senses and the power of memory alone, could never inspire.

Thus then we have embraced the earth in our reflections, and did time permit we could push our inquiries so as to make them enfold the sun and moon, for both of these bodies act like magnets upon the needle. And, quitting the confines of a special force, which I have taken merely to illustrate the manner in which physical science ought to be studied, we might permit our vision to range through Nature at large; and we should then observe, as I affirmed at the outset, that none of her agencies are isolated, that

"All are but parts of one stupendous whole;"

Parts, moreover, so related to each other as to be mutually convertible, and so subjected to quantitative laws that no force, nor any portion of a force, can make its appearance without an equivalent expenditure of some other power. The system of nature is thus proved to be a system of necessary connexion. I cannot expect you to realize this with the vividness of those whose minds by special culture or sympathy have become, to a great extent, reflectors of natural truth. But the more nearly you approximate to this conviction the more deeply you will feel how utterly headthenish and besotted it is to assume those disturbances of natural laws which weak men and women now daily assume and believe in. And as your studies advance, you will remark that in the assertion of this principle of interdependence Nature makes no difference between her smallest and her largest phenomena; in the land of LAW, the links forged from the former are just as strong as those formed from the latter. The laws of molecular attraction are as perfectly illustrated by the curvature of a dew-drop as by the rounding of a moon. It would take the same exercise of power to dissolve

the connexion of the faintest cloud, or the lightest shower of rain, with its antecedents and consequents, as to abolish the force which holds the material universe together. And should men, or nations, feel it to be their interest to assemble and ask for changes in the polity of our atmosphere, Science, though incompetent to prove them wrong, may at least preserve them from the error of under-rating the magnitude of their own demand. She informs them that in offering such petitions they are requesting the Creator to destroy the very solder of the universe. She tells them that their act is qualitatively the same as if they sought by prayers to avert the next solar eclipse, to reverse the tidal wave, to quench a conflagration, or to cause the Thames to flow up hill. Science cannot prove these things impossible to "the prayer of faith," but she may, by clearly stating the truth, show that Piety often asks for more than she intends,—more, indeed, than would be wholesome for either her or the world to have granted to her.

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Science and Art Department of the Committee of  
Council on Education.

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LECTURES  
ADDRESSED TO TEACHERS  
ON  
PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES  
AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE IV.

---

ON ZOOLOGY;

DELIVERED AT  
THE SOUTH KENSINGTON MUSEUM,  
14th May 1860,

BY  
PROFESSOR HUXLEY, F.R.S.



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## LECTURE.

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NATURAL HISTORY is the name familiarly applied to the study of the properties of such natural bodies as minerals, plants, and animals; the sciences which embody the knowledge man has acquired upon these subjects are commonly termed Natural Sciences, in contradistinction to other, so called "physical," sciences; and those who devote themselves especially to the pursuit of such sciences have been, and are, commonly termed "Naturalists."

Linnæus was a naturalist in this wide sense, and his "*Systema Naturæ*" was a work upon natural history in the broadest acceptation of the term; in it, that great methodizing spirit embodied all that was known in his time of the distinctive characters of minerals, animals, and plants. But the enormous stimulus which Linnæus gave to the investigation of nature soon rendered it impossible that any one man should write another "*Systema Naturæ*," and extremely difficult for any one to become a naturalist such as Linnæus was.

Great as have been the advances made by all the three branches of science, of old included under the title of natural history, there can be no doubt that zoology and botany have grown in an enormously greater ratio than mineralogy, and hence, as I suppose, the name of "natural history" has gradually become more and more definitely attached to these prominent divisions of the subject, and by "naturalist" people have meant more and more distinctly to imply a student of the structure and functions of living beings.

However this may be, it is certain that the advance of knowledge has gradually widened the distance between mineralogy and its old associates, while it has drawn zoology and botany closer together; so that of late years it has been found convenient (and indeed necessary) to associate the sciences which deal with vitality and all its phenomena under the common head of "biology;" and the biologists have come to repudiate any blood-relationship with their foster-brothers, the mineralogists.

Certain broad laws have a general application throughout both the animal and the vegetable worlds, but the ground common to these kingdoms of nature is not of very wide extent, and the multiplicity of details is so great, that the student of living beings finds himself obliged to devote his attention exclusively either to the one or the other. If he elects to study plants, under any aspect, we know at once what to call him; he is a botanist and his science is botany. But if the investigation of animal life be his choice, the name generally applied to him will vary, according to the kind of animals he studies, or the particular phenomena of animal life to which he confines his attention. If the study of man is his object, he is called an anatomist, or a physiologist, or an ethnologist; but if he dissects animals, or examines into the mode in which their functions are performed, he is a comparative anatomist or comparative physiologist. If he turns his attention to fossil animals he is a palæontologist. If his mind is more particularly directed to the



description, specific discrimination, classification, and distribution of animals he is termed a zoologist.

For the purposes of the present discourse, however, I shall recognize none of these titles save the last, which I shall employ as the equivalent of botanist, and I shall use the term zoology as denoting the whole doctrine of animal life, in contradistinction from botany, which signifies the whole doctrine of vegetable life.

Employed in this sense, zoology, like botany, is divisible into three great but subordinate sciences, morphology, physiology, and distribution, each of which may, to a very great extent, be studied independently of the other.

Zoological morphology is the doctrine of animal form or structure. Anatomy is one of its branches, development is another; while classification is the expression of the relations which different animals bear to one another, in respect of their anatomy and their development.

Zoological distribution is the study of animals in relation to the terrestrial conditions which obtain now, or have obtained at any previous epoch of the earth's history.

Zoological physiology, lastly, is the doctrine of the functions or actions of animals. It regards animal bodies as machines impelled by certain forces, and performing an amount of work, which can be expressed in terms of the ordinary forces of nature. The final object of physiology is to deduce the facts of morphology on the one hand, and those of distribution on the other, from the laws of the molecular forces of matter.

Such is the scope of zoology. But if I were to content myself with the enunciation of these dry definitions, I should ill exemplify that method of teaching this branch of physical science, which it is my chief business to-night to recommend. Let us turn away then from abstract definitions. Let us take some concrete living thing, some animal, the commoner the better, and let us see how the application of common sense and common logic to the obvious facts it presents, inevitably leads us into all these branches of zoological science.

I have before me a lobster. When I examine it, what appears to be the most striking character it presents? Why, I observe that this part which we call the tail of the lobster, is made up of six distinct hard rings and a seventh terminal piece. If I separate one of the middle rings, say the third, I find it carries upon its under surface a pair of limbs or appendages, each of which consists of a stalk and two terminal pieces. So that I can represent a transverse section of the ring and its appendages upon the diagram board in this way.

If I now take the fourth ring I find it has the same structure, and so have the fifth and the second; so that in each of these divisions of the tail I find parts which correspond with one another, a ring and two appendages; and in each appendage a stalk and two end pieces. "These corresponding parts are called in the technical language of anatomy "homologous parts." The ring of the third division is the "homologue" of the ring of the fifth, the appendage of the former is the homologue of the appendage of the latter. And as each division exhibits corresponding parts in corresponding places, we say that all the divisions are constructed upon the same plan. But now let us consider the sixth division. It is similar to, and yet different from, the others. The ring is essentially the same as in the other divisions; but the appendages look at first as if they were very different; and yet when we regard them closely, what do we find? A stalk and two

terminal divisions exactly as in the others, but the stalk is very short and very thick, the terminal divisions are very broad and flat, and one of them is divided into two pieces.

I may say, therefore, that the sixth segment is like the others in plan, but that it is modified in its details.

The first segment is like the others, so far as its ring is concerned, and though its appendages differ from any of those yet examined in the simplicity of their structure, parts corresponding with the stem and one of the divisions of the appendages of the other segments can be readily discerned in them.

Thus it appears that the lobster's tail is composed of a series of segments which are fundamentally similar, though each presents peculiar modifications of the plan common to all. But when I turn to the fore part of the body I see, at first, nothing but a great shield-like shell, called technically the "carapace," ending in front in a sharp spine, on either side of which are the curious compound eyes, set upon the ends of stout moveable stalks. Behind these, on the under side of the body, are two pairs of long feelers or antennæ, followed by six pairs of jaws, folded against one another over the mouth, and five pairs of legs, the foremost of these being the great pinchers, or claws, of the lobster.

It looks, at first, a little hopeless to attempt to find in this complex mass a series of rings, each with its pair of appendages, such as I have shown you in the abdomen, and yet it is not difficult to demonstrate their existence. Strip off the legs, and you will find that each pair is attached to a very definite segment of the under wall of the body; but these segments, instead of being the lower parts of free rings, as in the tail, are such parts of rings which are all solidly united and bound together; and the like is true of the jaws, the feelers, and the eye-stalks, every pair of which is borne upon its own special segment. Thus the conclusion is gradually forced upon us that the body of the lobster is composed of as many rings as there are pairs of appendages, namely, twenty in all, but that the six hindmost rings remain free and moveable, while the fourteen front rings become firmly soldered together, their backs forming one continuous shield—the carapace.

Unity of plan, diversity in execution, is the lesson taught by the study of the rings of the body, and the same instruction is given still more emphatically by the appendages. If I examine the outermost jaw I find it consists of three distinct portions, an inner, a middle, and an outer, mounted upon a common stem; and if I compare this jaw with the legs behind it, or the jaws in front of it, I find it quite easy to see, that, in the legs, it is the part of the appendage which corresponds with the inner division, which becomes modified into what we know familiarly as the "leg," while the middle division disappears, and the outer division is hidden under the carapace. Nor is it more difficult to discern that, in the appendages of the tail, the middle division appears again and the outer vanishes; while on the other hand, in the foremost jaw, the so-called mandible, the inner division only is left; and, in the same way, the parts of the feelers and of the eye-stalks, can be identified with those of the legs and jaws.

But whither does all this tend? To the very remarkable conclusion that a unity of plan, of the same kind as that discoverable in the tail or abdomen of the lobster, pervades the whole organization of its skeleton, so that I can return to the diagram representing any one of the rings of the tail, which I drew upon the board, and by adding a third division to each appendage, I can use it as a sort of



scheme or plan of any ring of the body. I can give names to all the parts of that figure, and then if I take any segment of the body of the lobster, I can point out to you exactly, what modification the general plan has undergone in that particular segment; what part has remained moveable and what has become fixed to another; what has been excessively developed and metamorphosed, and what has been suppressed.

But I imagine I hear the question, how is all this to be tested? No doubt it is a pretty and ingenious way of looking at the structure of any animal, but is it anything more? Does Nature acknowledge in any deeper way this unity of plan we seem to trace?

The objection suggested by these questions is a very valid and important one, and morphology was in an unsound state, so long as it rested upon the mere perception of the analogies which obtain between fully formed parts. The unchecked ingenuity of speculative anatomists proved itself fully competent to spin any number of contradictory hypotheses out of the same facts, and endless morphological dreams threatened to supplant scientific theory.

Happily, however, there is a criterion of morphological truth, and a sure test of all homologies. Our lobster has not always been what we see it; it was once an egg, a semifluid mass of yolk, not so big as a pin's head, contained in a transparent membrane, and exhibiting not the least trace of any one of those organs, whose multiplicity and complexity, in the adult, are so surprising. After a time a delicate patch of cellular membrane appeared upon one face of this yolk, and that patch was the foundation of the whole creature, the clay out of which it would be moulded. Gradually investing the yolk, it became subdivided by transverse constrictions into segments, the fore-runners of the rings of the body. Upon the ventral surface of each of the rings thus sketched out, a pair of bud-like prominences made their appearance—the rudiments of the appendages of the ring. At first, all the appendages were alike, but, as they grew, most of them became distinguished with a stem and two terminal divisions, to which in the middle part of the body was added a third outer division; and it was only at a later period, that by the modification, or abortion, of certain of these primitive constituents, the limbs acquired their perfect form.

Thus the study of development proves that the doctrine of unity of plan is not merely a fancy, that it is not merely one way of looking at the matter, but that it is the expression of deep-seated natural facts. The legs and jaws of the lobster may not merely be regarded as modifications of a common type,—in fact and in nature they are so,—the leg and the jaw of the young animal being, at first, indistinguishable.

These are wonderful truths, the more so because the zoologist finds them to be of universal application. The investigation of a polype, of a snail, of a fish, of a horse, or of a man would have led us, though by a less easy path, perhaps, to exactly the same point. Unity of plan everywhere lies hidden under the mask of diversity of structure—the complex is everywhere evolved out of the simple. Every animal has at first the form of an egg, and every animal and every organic part, in reaching its adult state, passes through conditions common to other animals and other adult parts; and this leads me to another point. I have hitherto spoken as if the lobster were alone in the world, but, as I need hardly remind you, there are myriads of other animal organisms. Of these some, such as men, horses, birds, fishes, snails, slugs, oysters, corals, and sponges, are not in the least like the lobster. But other animals, though they may differ a good deal

from the lobster, are yet either very like it, or are like something that is like it. The cray fish, the rock lobster, and the prawn, and the shrimp, for example, however different, are yet so like lobsters, that a child would group them as of the lobster kind, in contradistinction to snails and slugs; and these last again would form a kind by themselves, in contradistinction to cows, horses, and sheep, the cattle kind.

But this spontaneous grouping into "kinds" is the first essay of the human mind at classification, or the calling by a common name of those things that are alike, and the arranging them in such a manner as best to suggest the sum of their likenesses and unlikenesses to other things.

Those kinds which include no other subdivisions than the sexes, or various breeds, are called, in technical language, species. The English lobster is a species, our cray fish is another, our prawn is another. In other countries, however, there are lobsters, cray fish, and prawns, very like ours, and yet presenting sufficient differences to deserve distinction. Naturalists, therefore, express this resemblance and this diversity by grouping them as distinct species of the same "genus." But the lobster and the cray fish, though belonging to distinct genera, have many features in common, and hence are grouped together in an assemblage which is called a family. More distant resemblances connect the lobster with the prawn and the crab, which are expressed by putting all these into the same order. Again, more remote, but still very definite, resemblances unite the lobster with the woodlouse, the king crab, the water-flea, and the barnacle, and separate them from all other animals; whence they collectively constitute the larger group, or class, *Crustacea*. But the *Crustacea* exhibit many peculiar features in common with insects, spiders, and centipedes, so that these are grouped into the still larger assemblage or "province" *Articulata*, and, finally, the relations which these have to worms and other lower animals, are expressed by combining the whole vast aggregate into the subkingdom *Annulosa*.

If I had worked my way from a sponge instead of a lobster, I should have found it associated, by like ties, with a great number of other animals into the subkingdom *Protozoa*; if I had selected a fresh-water polype or a coral, the members of what naturalists term the subkingdom *Cœlenterata*, would have grouped themselves around my type; had a snail been chosen, the inhabitants of all univalve and bivalve, land and water shells, the lamp shells, the squids, and the sea-mat would have gradually linked themselves on to it as members of the same subkingdom of *Mollusca*; and finally, starting from man, I should have been compelled to admit first, the ape, the rat, the horse, the dog, into the same class, and then the bird, the crocodile, the turtle, the frog, and the fish, into the same subkingdom of *Vertebrata*.

And if I had followed out all these various lines of classification fully, I should discover in the end that there was no animal, either recent or fossil, which did not at once fall into one or other of these subkingdoms. In other words, every animal is organized upon one or other of the five, or more, plans, whose existence renders our classification possible. And so definitely and precisely marked is the structure of each animal, that, in the present state of our knowledge, there is not the least evidence to prove that a form, in the slightest degree transitional between any two of the groups *Vertebrata*, *Annulosa*, *Mollusca*, and *Cœlenterata*, either exists, or has existed, during that period of the earth's history which is recorded by the geologist.



Nevertheless, you must not for a moment suppose, because no such transitional forms are known, that the members of the subkingdoms are disconnected from, or independent of, one another. On the contrary, in their earliest condition they are all alike, and the primordial germs of a man, a dog, a bird, a fish, a beetle, a snail, and a polype are in no essential structural respects, distinguishable.

In this broad sense, it may with truth be said, that all living animals, and all those dead creations which geology reveals, are bound together by an all-pervading unity of organization, of the same character, though not equal in degree, to that which enables us to discern one and the same plan amidst the twenty different segments of a lobster's body. Truly it has been said, that to a clear eye the smallest fact is a window through which the Infinite may be seen.

Turning from these purely morphological considerations, let us now examine into the manner in which the attentive study of the lobster impels us into other lines of research.

Lobsters are found in all the European seas; but on the opposite shores of the Atlantic and in the seas of the southern hemisphere they do not exist. They are, however, represented in these regions by very closely allied, but distinct forms—the *Homarus Americanus* and the *Homarus Capensis*, so that we may say that the European has one species of *Homarus*; the American, another; the African, another; and thus the remarkable facts of geographical distribution begin to dawn upon us.

Again, if we examine the contents of the earth's crust, we shall find in the later of those deposits, which have served as the great burying grounds of past ages, numberless lobster-like animals, but none so similar to our living lobster as to make zoologists sure that they belonged even to the same genus. If we go still further back in time, we discover in the oldest rocks of all, the remains of animals, constructed on the same general plan as the lobster, and belonging to the same great group of *Crustacea*; but for the most part totally different from the lobster, and indeed from any other living form of crustacean; and thus we gain a notion of that successive change of the animal population of the globe, in past ages, which is the most striking fact revealed by geology.

Consider, now, where our inquiries have led us. We studied our type morphologically, when we determined its anatomy and its development, and when comparing it, in these respects, with other animals, we made out its place in a system of classification. If we were to examine every animal in a similar manner we should establish a complete body of zoological morphology.

Again, we investigated the distribution of our type in space and in time, and, if the like had been done with every animal, the sciences of geographical and geological distribution would have attained their limit.

But you will observe one remarkable circumstance, that, up to this point, the question of the life of these organisms has not come under consideration. Morphology and distribution might be studied almost as well, if animals and plants were a peculiar kind of crystals and possessed none of those functions which distinguish living beings so remarkably. But the facts of morphology and distribution have to be accounted for, and the science, whose aim it is to account for them, is physiology.

Let us return to our lobster once more. If we watched the creature in its native element, we should see it climbing actively the submerged rocks, among which it delights to live, by means of its strong legs; or swimming by powerful strokes of its great tail, the appendages

of whose sixth joint are spread out into a broad fan-like propeller; seize it and it will show you that its great claws are no mean weapons of offence; suspend a piece of carrion among its haunts, and it will greedily devour it, tearing and crushing the flesh by means of its multitudinous jaws.

Suppose that we had known nothing of the lobster but as an inert mass, an organic crystal, if I may use the phrase, and that we could suddenly see it exerting all these powers, what wonderful new ideas and new questions would arise in our minds! The great new question would be "How does all this take place?" the chief new idea would be the idea of adaptation to purpose,—the notion that the constituents of animal bodies are not mere unconnected parts, but organs working together to an end. Let us consider the tail of the lobster again from this point of view. Morphology has taught us that it is a series of segments composed of homologous parts, which undergo various modifications—beneath and through which a common plan of formation is discernible. But if I look at the same part physiologically, I see that it is a most beautifully constructed organ of locomotion, by means of which the animal can swiftly propel itself either backwards or forwards.

But how is this remarkable propulsive machine made to perform its functions? If I were suddenly to kill one of these animals and to take out all the soft parts, I should find the shell to be perfectly inert, to have no more power of moving itself than is possessed by the machinery of a mill, when disconnected from its steam-engine or water-wheel. But if I were to open it, and take out the viscera only, leaving the white flesh, I should perceive that the lobster could bend and extend its tail as well as before. If I were to cut off the tail I should cease to find any spontaneous motion in it—but on pinching any portion of the flesh, I should observe that it underwent a very curious change—each fibre becoming shorter and thicker. By this act of contraction, as it is termed, the parts to which the ends of the fibre are attached are, of course, approximated—and according to the relations of their points of attachment to the centres of motion of the different rings, the bending or the extension of the tail results. Close observation of the newly opened lobster would soon show that all its movements are due to the same cause—the shortening and thickening of these fleshy fibres, which are technically called muscles.

Here, then, is a capital fact. The movements of the lobster are due to muscular contractility. But why does a muscle contract at one time and not at another? Why does one whole group of muscles contract when the lobster wishes to extend its tail, and another group, when he desires to bend it? What is it originates, directs and controls, the motive power?

Experiment, the great instrument for the ascertainment of truth in physical science, answers this question for us. In the head of the lobster there lies a small mass of that peculiar tissue which is known as nervous substance. Cords of similar matter connect this brain of the lobster, directly or indirectly, with the muscles. Now, if these communicating cords are cut, the brain remaining entire, the power of exerting what we call voluntary motion in the parts below the section is destroyed, and on the other hand, if, the cords remaining entire, the brain mass be destroyed, the same voluntary mobility is equally lost. Whence the inevitable conclusion is, that the power of originating these motions resides in the brain, and is propagated along the nervous cords.

In the higher animals the phenomena which attend this trans-



mission have been investigated, and the exertion of the peculiar energy which resides in the nerves, has been found to be accompanied by a disturbance of the electrical state of their molecules.

If we could exactly estimate the signification of this disturbance; if we could obtain the value of a given exertion of nerve force by determining the quantity of electricity or of heat of which it is the equivalent; if we could ascertain upon what arrangement, or other condition of the molecules of matter, the manifestation of the nervous and muscular energies depends, (and doubtless science will some day or other ascertain these points,) physiologists would have attained their ultimate goal in this direction; they would have determined the relation of the motive force of animals to the other forms of force found in nature; and if the same process had been successfully performed for all the operations which are carried on, in and by, the animal frame, physiology would be perfect, and the facts of morphology and distribution would be deducible from the laws which physiologists had established, combined with those determining the condition of the surrounding universe.

There is not a fragment of the organism of this humble animal, whose study would not lead us into regions of thought as large as those which I have briefly opened up to you; but what I have been saying, I trust, has not only enabled you to form a conception of the scope and purport of zoology, but has given you an imperfect example of the manner in which, in my opinion, that science, or indeed any physical science, may be best taught. The great matter is to make teaching real and practical, by fixing the attention of the student on particular facts; but at the same time it should be rendered broad and comprehensive by constant reference to the generalizations of which all particular facts are illustrations. The lobster has served as a type of the whole animal kingdom, and its anatomy and physiology have illustrated for us some of the greatest truths of biology. The student who has once seen for himself the facts which I have described, has had their relations explained to him, and has clearly comprehended them, has so far a knowledge of zoology, which is real and genuine, however limited it may be, and which is worth more than all the mere reading knowledge of the science he could ever acquire. His zoological information is, so far, knowledge and not mere hearsay.

And if it were my business to fit you for the certificate in zoological science granted by this department, I should pursue a course precisely similar in principle to that which I have taken to night. I should select a fresh-water sponge, a fresh-water polype or a *Cyanæa*, a fresh water mussel, a lobster, a fowl, as types of the five primary divisions of the animal kingdom. I should explain their structure very fully, and show how each illustrated the great principles of zoology. Having gone very carefully and fully over this ground, I should feel that you had a safe foundation, and I should then take you in the same way, but less minutely, over similarly selected illustrative types of the classes; and then I should direct your attention to the special forms enumerated under the head of types, in this syllabus, and to the other facts there mentioned.

That would, speaking generally, be my plan. But I have undertaken to explain to you the best mode of acquiring and communicating a knowledge of zoology, and you may therefore fairly ask me for a more detailed and precise account of the manner in which I should propose to furnish you with the information I refer to.

My own impression is that the best model for all kinds of training in physical science is that afforded by the method of teaching

anatomy, in use in the medical schools. This method consists of three elements—lectures, demonstrations, and examinations.

The object of lectures is, in the first place, to awaken the attention and excite the enthusiasm of the student; and this, I am sure, may be effected to a far greater extent by the oral discourse and by the personal influence of a respected teacher, than in any other way. Secondly, lectures have the double use of guiding the student to the salient points of a subject, and at the same time forcing him to attend to the whole of it, and not merely to that part which takes his fancy. And lastly, lectures afford the student the opportunity of seeking explanations of those difficulties which will, and indeed ought to, arise in the course of his studies.

But for a student to derive the utmost possible value from lectures, several precautions are needful.

I have a strong impression that the better a discourse is, as an oration, the worse it is as a lecture. The flow of the discourse carries you on without proper attention to its sense; you drop a word or a phrase, you lose the exact meaning for a moment, and while you strive to recover yourself, the speaker has passed on to something else.

The practice I have adopted of late years in lecturing to students, is to condense the substance of the hour's discourse into a few dry propositions, which are read slowly and taken down from dictation; the reading of each being followed by a free commentary, expanding and illustrating the proposition, explaining terms, and removing any difficulties that may be attackable in that way, by diagrams made roughly, and seen to grow under the lecturer's hand. In this manner you, at any rate, insure the co-operation of the student to a certain extent. He cannot leave the lecture-room entirely empty if the taking of notes is enforced, and a student must be preternaturally dull and mechanical if he can take notes and hear them properly explained, and yet learn nothing.

What books shall I read? is a question constantly put by the student to teacher. My reply usually is, "None; write your notes out carefully and fully; strive to understand them thoroughly; come to me for the explanation of anything you cannot understand, and I would rather you did not distract your mind by reading." A properly composed course of lectures ought to contain fully as much matter as a student can assimilate in the time occupied by its delivery; and the teacher should always recollect that his business is to feed, and not to cram, the intellect. Indeed, I believe that a student who gains from a course of lectures the simple habit of concentrating his attention upon a definitely limited series of facts, until they are thoroughly mastered, has made a step of immeasurable importance.

But however good lectures may be, and however extensive the course of reading by which they are followed up, they are but accessories to the great instrument of scientific teaching—demonstration. If I insist unweariedly, nay fanatically, upon the importance of physical science as an educational agent, it is because the study of any branch of science, if properly conducted, appears to me to fill up a void left by all other means of education. I have the greatest respect and love for literature; nothing would grieve me more than to see literary training other than a very prominent branch of education; indeed, I wish that real literary discipline were far more attended to than it is; but I cannot shut my eyes to the fact that there is a vast difference between men who have had a purely literary, and those who have had a sound scientific, training.



Seeking for the cause of this difference, I imagine I can find it in the fact, that, in the world of letters, learning and knowledge are one, and books are the source of both; whereas in science, as in life, learning and knowledge are distinct, and the study of things, and not of books, is the source of the latter.

All that literature has to bestow may be obtained by reading and by practical exercise in writing and in speaking; but I do not exaggerate when I say, that none of the best gifts of science are to be won by these means. On the contrary, the great benefit which a scientific education bestows, whether as training or as knowledge, is dependent upon the extent to which the mind of the student is brought into immediate contact with facts—upon the degree to which he learns the habit of appealing directly to nature, and of acquiring through his senses concrete images of those properties of things, which are and always will be, but approximatively expressed in human language. Our way of looking at nature, and of speaking about her, varies from year to year; but a fact once seen, a relation of cause and effect, once demonstratively apprehended, are possessions which neither change nor pass away, but, on the contrary, form fixed centres, about which other truths aggregate by natural affinity.

Therefore, the great business of the scientific teacher is, to imprint the fundamental, irrefragable, facts of his science, not only by words upon the mind, but by sensible impressions upon the eye and ear and touch, of the student, in so complete a manner that every term used, or law enunciated, should afterwards call up vivid images of the particular structural, or other, facts which furnished the demonstration of the law, or the illustration of the term.

Now this important operation can only be achieved by constant demonstration, which may take place to a certain imperfect extent during a lecture, but which ought also to be carried on independently, and which should be addressed to each individual student, the teacher endeavouring, not so much to show a thing to the learner, as to make him see it for himself.

I am well aware that there are great practical difficulties in the way of effectual zoological demonstrations. The dissection of animals is not altogether pleasant, and requires much time; nor is it easy to secure an adequate supply of the needful specimens. The botanist has here a great advantage; his specimens are easily obtained, are clean and wholesome, and can be dissected in a private house as well as anywhere else; and hence, I believe, the fact, that botany is so much more readily and better taught than its sister science. But, be it difficult or be it easy, if zoological science is to be properly studied, demonstration, and, consequently, dissection, must be had. Without it, no man can have a really sound knowledge of animal organization.

A good deal may be done, however, without actual dissection on the student's part, by demonstration upon specimens and preparations, and in all probability it would not be very difficult, were the demand sufficient, to organize collections of such objects, sufficient for all the purposes of elementary teaching, at a comparatively cheap rate. Even without these, much might be effected, if the zoological collections, which are open to the public, were arranged according to what has been termed the "typical principle;" that is to say, if the specimens exposed to public view were so selected, that the public could learn something from them, instead of being, as at present, merely confused by their multiplicity. For example, the grand ornithological gallery at the

British Museum contains between two and three thousand species of birds, and sometimes five or six specimens of a species. They are very pretty to look at and some of the cases are, indeed, splendid; but I will undertake to say, that no man but a professed ornithologist has ever gathered much information from the collection. Certainly, no one of the tens of thousands of the general public who have walked through that gallery ever knew more about the essential peculiarities of birds when he left the gallery, than when he entered it. But if, somewhere in that vast hall, there were a few preparations, exemplifying the leading structural peculiarities and the mode of development of a common fowl; if the types of the genera, the leading modifications in the skeleton, in the plumage at various ages, in the mode of nidification, and the like, among birds, were displayed; and if the other specimens were put away in a place where the men of science, to whom they are alone useful, could have free access to them, I can conceive that this collection might become a great instrument of scientific education.

The last implement of the teacher to which I have adverted is examination—a means of education now so thoroughly understood that I need hardly enlarge upon it. I hold that both written and oral examinations are indispensable, and, by requiring the description of specimens, they may be made to supplement demonstration.

Such is the fullest reply the time at my disposal will allow me to give to the question—how may a knowledge of zoology be best acquired and communicated?

But there is a previous question which may be moved, and which, in fact, I know many are inclined to move. It is the question why should training masters be encouraged to acquire a knowledge of this, or any other branch, of physical science? What is the use, it is said, of attempting to make physical science a branch of primary education? Is it not probable that teachers, in pursuing such studies, will be led astray from the acquirement of more important but less attractive knowledge? and, even if they can learn something of science without prejudice to their usefulness, what is the good of their attempting to instil that knowledge into boys whose real business is the acquisition of reading, writing, and arithmetic?

These questions are, and will be, very commonly asked, for they arise from that profound ignorance of the value and true position of physical science, which infests the minds of the most highly educated and intelligent classes of the community. But if I did not feel well assured that they are capable of being easily and satisfactorily answered; that they have been answered over and over again; and that the time will come when men of liberal education will blush to raise such questions,—I should be ashamed of my position here to-night. Without doubt, it is your great and very important function to carry out elementary education; without question, anything that should interfere with the faithful fulfilment of that duty on your part would be a great evil; and if I thought that your acquirement of the elements of physical science and your communication of those elements to your pupils, involved any sort of interference with your proper duties, I should be the first person to protest against your being encouraged to do anything of the kind.

But is it true that the acquisition of such a knowledge of science as is proposed, and the communication of that knowledge, are calculated to weaken your usefulness? or may I not rather ask is it possible for you to discharge your functions properly, without these aids?



What is the purpose of primary intellectual education? I apprehend that its first object is to train the young in the use of those tools wherewith men extract knowledge from the ever-shifting succession of phenomena which pass before their eyes; and that its second object is to inform them of the fundamental laws which have been found by experience to govern the course of things, so that they may be not turned out into the world naked, defenceless, and a prey to the events they might control.

A boy is taught to read his own and other languages, in order that he may have access to infinitely wider stores of knowledge than could ever be opened to him by oral intercourse with his fellow men; he learns to write, that his means of communication with the rest of mankind may be indefinitely enlarged, and that he may record and store up the knowledge he acquires. He is taught elementary mathematics that he may understand all those relations of number and form, upon which the transactions of men, associated in complicated societies, are built, and that he may have some practice in deductive reasoning.

All these operations of reading, writing, and ciphering, are intellectual tools whose use should, before all things, be learned, and learned thoroughly; so that the youth may be enabled to make his life that which it ought to be, a continual progress in learning and in wisdom.

But in addition, primary education endeavours to fit a boy out with a certain equipment of positive knowledge. He is taught the great laws of morality; the religion of his sect; so much history and geography as will tell him where the great countries of the world are, what they are, and how they have become what they are.

Without doubt all these are most fitting and excellent things to teach a boy; I should be very sorry to omit any of them from any scheme of primary intellectual education. The system is excellent so far as it goes.

But if I regard it closely a curious reflection arises. I suppose that fifteen hundred years ago, the child of any well-to-do Roman citizen was taught just these same things; reading and writing in his own and, perhaps, the Greek tongue; the elements of mathematics; and the religion, morality, history, and geography current in his time. Furthermore, I do not think I err in affirming, that, if such a Christian Roman boy, who had finished his education, could be transplanted into one of our public schools, and pass through its course of instruction, he would not meet with a single unfamiliar line of thought; amidst all the new facts he would have to learn, not one would suggest a different mode of regarding the universe from that current in his own time.

And yet surely there is some great difference between the civilization of the fourth century and that of the nineteenth, and still more between the intellectual habits and tone of thought of that day and of this?

And what has made this difference? I answer fearlessly: The prodigious development of physical science within the last two centuries.

Modern civilization rests upon physical science; take away her gifts to our own country, and our position among the leading nations of the world is gone to-morrow; for it is physical science only, that makes intelligence and moral energy stronger than brute force.

The whole of modern thought is steeped in science; it has made its way into the works of our best poets, and even the mere man of letters, who affects to ignore and despise science, is unconsciously impregnated with her spirit and indebted for his best products to her

methods. I believe that the greatest intellectual revolution mankind has yet seen is now slowly taking place by her agency. She is teaching the world that the ultimate court of appeal is observation and experiment, and not authority; she is teaching it to estimate the value of evidence; she is creating a firm and living faith in the existence of immutable moral and physical laws, perfect obedience to which is the highest possible aim of an intelligent being.

But of all this your old stereotyped system of education takes no note. Physical science, its methods, its problems and its difficulties will meet the poorest boy at every turn, and yet we educate him in such a manner that he shall enter the world, as ignorant of the existence of the methods and facts of science, as the day he was born. The modern world is full of artillery; and we turn out our children to do battle in it, equipped with the shield and sword of an ancient gladiator.

Posterity will cry shame on us if we do not remedy this deplorable state of things. Nay, if we live twenty years longer, our own consciences will cry shame on us.

It is my firm conviction that the only way to remedy it is to make the elements of physical science an integral part of primary education. I have endeavoured to show you how that may be done for that branch of science which it is my business to pursue; and I can but add, that I should look upon the day when every schoolmaster throughout this land was a centre of genuine, however rudimentary, scientific knowledge, as an epoch in the history of the country.

But let me entreat you to remember my last words. Mere book learning in physical science, is a sham and a delusion—what you teach, unless you wish to be impostors, that you must first know; and real knowledge in science, means personal acquaintance with the facts, be they few or many.

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NOTE.—I am reminded that “the aid granted by the Science and Art Department to science instruction is, at present, almost wholly limited to adult instruction in mechanics’ institutions and evening classes.”

The fact, that the wise efforts of those who planned the scheme, which I had in my mind, when this lecture was delivered, should have been partially nullified, however, renders my remarks more, and not less, applicable; and if I were inclined to alter them at all, it would only be to increase their force.

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#### LONDON:

Printed by GEORGE E. EYRE and WILLIAM SPOTTISWOODE,  
Printers to the Queen's most Excellent Majesty.

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Science and Art Department of the Committee of  
Council on Education.

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## LECTURES

ADDRESSED TO TEACHERS

ON

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE

METHOD OF TEACHING A SCIENCE CLASS.

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### LECTURE V.

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### ON MINERALOGY;

DELIVERED AT

THE SOUTH KENSINGTON MUSEUM.

7th May 1860.

BY

W. W. SMYTH, M.A., F.R.S., G.S.

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LONDON:

PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,  
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.  
FOR HER MAJESTY'S STATIONERY OFFICE.

1860.

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*Price Twopence.*







## LECTURE.

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WHEN we compare the popular literature of 150 years ago with that of our own times, we must be struck, in the first place, with the enormous extension of the writings addressed in recent times to an educated body in the reading public; and in the second place, as regards exact knowledge, with the greatly improved tone in which the pursuits and cultivators of the various branches of physical science are regarded by all classes of authors at the present day. Addison, writing in 1710, could admit that "Nature is full of wonders; every atom is a standing miracle, and endowed with such qualities as could not be impressed on it by a person and wisdom less than infinite;" yet he considered himself almost in the same breath called upon to apologise for the then unappreciated zeal of collectors of objects of natural history, and added, "It is, indeed, wonderful to consider that there should be a sort of learned men, who are wholly employed in gathering together the refuse of Nature, if I may call it so, and hoarding up in their chests and cabinets such creatures as others industriously avoid the sight of."\* The modern appreciation of scientific work, and of the truths founded upon it, as well as the strong desire felt in many quarters, to sow broadcast amid the people, a taste for and knowledge of the sciences, has sprung from a variety of sources, into which on the present occasion we have no need to inquire. Foremost, however, among them are doubtless some of those remarkable applications of scientific results to our material well-being, which have tended within a recent period to produce a palpable change in many of the aspects of society.

So general has become the conviction of the ennobling tendency, and, at the same time, of the utilitarian value of scientific pursuits, that few enemies now dare to show an avowed opposition; and if there occur occasional exhibitions of fear or dislike, or even of affected contempt, we may good-humouredly place them to the account of lingering prejudice or ignorance, and leave them to be expunged by the gradually advancing spread of enlightenment.

The object of the present Lecture being the consideration of the most advisable mode of studying Mineralogy, or the science which deals with the unmixed mineral substances, forming one of the great divisions of the Natural Kingdom, a few words as to its scope and objects may be premised, in order to clear away the indistinctness which still in some minds confounds all the inorganic or stony materials of our globe. Half a century since, and the term Mineralogy might be held to include that vigorous science Geology, which has, under the united efforts of a small band of earnest labourers, within a brief period totally altered our views of the architecture of the world. At the present day, it must be limited to the study, as a branch of Natural History, of those unorganized substances, in which a constant uniformity of composition, and very generally a tendency to occur in particular and essential forms, point to the propriety of establishing species analogous to those of animals and

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\* Tatler, 26th August 1710.



plants. Strange that a division of the productions of nature, embracing so many substances of the highest value to civilised man, should not, until very recently, have been included within the domain of an exact science! But as the arts have almost invariably preceded the sciences to which they are related, men have for thousands of years smelted the metals from their ores, decked themselves with gems, built their dwellings, and formed their implements, their arms, and ornaments of many of the stony minerals, without obtaining a true perception of the relations between their various characters. Even careful observers have collected facts, and multiplied lucubrations upon these products of nature; and yet the writings of a Dioscorides, of a Theophrastus, and a Pliny, interesting and valuable as they may be, are a warning and a beacon to our later generation, that mere art, mere labour, and mere zeal are altogether insufficient to attain the object required, and that without the method of science to invigorate the tree of knowledge, the once promising blossoms must wither, the fruit can never ripen.

If we would learn, on the one hand, how great is the importance of systematizing observation, and, on the other, how the mutual connexion of various physical sciences renders it impossible greatly to advance the one without a corresponding progression in others, nothing can be more instructive than to watch the progress of mineralogy in the times approaching to our own. From the sixteenth century downwards, even after the principles of the Baconian philosophy had been fully appreciated, we find that many authors of undoubted industry and talent accumulated materials, which, for lack of the breath of life, to be infused by science alone, remained a mere body of unmanageable lumber. Albertus Magnus, Agricola, Leonardus, Boetius de Boodt, Hill, Henckel, and others, have added somewhat to the store of knowledge handed down by the older compilers. Yet the whole of their varied matter, uninspired by any rational insight into the relation between allied substances, leaves but a fragmentary impression on the mind instead of that harmonious colouring, which must, when they are viewed aright, unite, and yet enable us to distinguish the objects presented by any one of the divisions of nature. The absence at that period of a chemical science and of careful determination of form left none but accidental or untrustworthy bonds of union between different inorganic bodies, and, under the prevailing peculiar views of religion, often introduced a superstitious mysticism to solve questions fully within the domain of human inquiry. Certain wonderful effects being thus admitted, on somewhat slight evidence, to be produced by particular gems, we are reminded that "no one will attribute these faculties to the precious stone as natural to it, but only to the spirits to whom God hath permitted and committed the exercise of such faculties. Perhaps the substance of the gems, in consequence of their beauty, their lustre, and their dignity, is considered suitable for the dwelling and receptacle of good spirits; and thus when marvellous effects are operated by the precious stones, such are not to be attributed to their inherent properties, but to the spirits."\*

To Linnæus appears to be due the first attempt to introduce into mineralogy that systematic order and arrangement which he had so successfully applied to the organic kingdoms. He was rapidly followed by two other Swedish philosophers, Wallerius and Cronstedt, publishing their first editions in 1747 and 1758, who, now that chemistry had begun to unravel the secrets of the combination of elements, seized the clue thus offered them, and inaugurated systems placed on a reasonable basis. When, in addition, towards the end of the last century, the beautiful

\* Anselm Boetius de Boodt, *Histoire des Pierrieres*; Lyon, 1644; p. 158.

relations of crystalline forms were detected by the sagacity, and their laws followed out by the assiduity, of Romé de Lisle and Häuy, the science was established in a position which has from year to year been strengthened by the contributions of observers physical, mathematical, and chemical.

But before we may proceed to consider how this subject is to be taught, comes first and foremost the question, What is to be the end and aim of the teaching? There are two sides to the subject, that of pure science, and that of science applied to certain arts; on the one side the contemplation of the glorious works of God,—on the other, the reflection that some 40,000,000*l.* sterling is the value of the rough minerals annually raised in this our United Kingdom. Are the two incompatible? I believe by no means. A patient and sufficient study of mineralogy, even if intended for application to practical ends, must infallibly arouse admiration for the marvels of creation, and the deepest veneration for its Author. Well has it been said by the most brilliant of our writers on art:—  
 “There are no natural objects out of which more can be learned than  
 “out of stones. They seem to have been created especially to reward a  
 “patient observer. Nearly all other objects in nature can be seen to  
 “some extent without patience, and are pleasant even in being half seen.  
 “Trees, clouds, and rivers are enjoyable even by the careless; but the  
 “stone under his foot has for carelessness nothing in it but stumbling;  
 “no pleasure is languidly to be had out of it, nor food, nor good of any  
 “kind; nothing but symbolism of the hard heart, and the unfatherly  
 “gift. And yet, do but give it some reverence and watchfulness, and  
 “there is bread of thought in it, more than in any other lowly feature of  
 “all the landscape.”—*Ruskin, Modern Painters*, iv., 311.

Yet another question remains to be solved, far more important for our special object in the present inquiry, and one to which I must beg your particular attention, as that one upon which the nature of the teaching must entirely hinge, and with which the success of the method to be adopted must stand or fall.

This question may be put as follows,—Is it proposed for any particular teacher, and as regards any particular class of pupils, to teach mineralogy as a portion of general education, or is it, as a special subject, to be directly applied in practical life? In the first case, it will be comparatively easy for schoolmasters to acquire that general knowledge of their subject which shall enable them to impart to their classes such an amount of information as may awake a feeling of admiration for the wonders of many almost unnoticed objects with which we are surrounded, and excite an interest which in some minds may lead to further study. But in the second case, the teacher must prepare to apply a more enduring attention, and must labour beyond the region of lectures and text-books, if he would qualify himself to deal with the varying conditions under which the primarily acquired knowledge will have to be applied. Both modes of treatment must in the outset be similar, and I shall, therefore, occupy your time chiefly in referring to the systematic study of the science without special application. But at a time like the present, when it is proposed to include mineralogy with other sciences in the examinations of so many public institutions and services, it is needful for the protection of those who are to be engaged in technical affairs to insist on the difference, and to protest against the notion that a few hours devoted to lectures and reading, and to the study of collections, can be sufficient to enable a teacher to cope with the difficulties of application to mining and metallurgy.

Let me point out, too, that there is a considerable and increasing demand for both classes. What with the premium offered by the competitive examinations, and the course of instruction at many schools and colleges, a moderate acquaintance with general mineralogy,



partly for its own sake and partly as a stepping-stone to geology, has become requisite. As regards the second, or more technical kind of instruction, let us remember that in our own kingdom upwards of 300,000 persons are constantly and directly employed in the mere raising of minerals. It is not to be expected that any large proportion of this great number should require to be initiated into the arcana of science; no more so, in fact, than that the rank and file of an army should study the mysteries of military tactics. What we want of the great bulk of them is to make skilful and robust workmen; but it is not too much to expect that the managers and the better qualified men of our thousands of mines should have the opportunity of becoming acquainted with the true characters and relations of the substances which form the basis of their calling. And the best proof of such a want is afforded by the numerous and constantly recurring efforts to establish technical schools in our mining districts. Some few, as those of Bristol, Wigan, and Glasgow, are in actual operation; whilst others, at Newcastle, Birmingham, Pool, Truro, and Swansea, have either been partially attempted or have been agitated for without present success. Each one of these, it has been hoped, might ultimately be the central institution in connexion with local schools of a humbler character, the number of which ought to be very considerable to carry the advantages of such an education down to those ranks which it is desired to benefit. With so large and so variously circumstanced a body there must necessarily be a gradation throughout, and were such a system established, those students who desired an instruction more detailed and complete than could be attained at the local schools would frequent the central district institutions. Those, again, whose means and future responsibilities warranted a still fuller course would, as now, complete a course of study at the Museum of Practical Geology, where the results of the survey in progress and the large collections would offer opportunities for scientific training which could not be expected in the provinces. And in closing these introductory remarks, I may be permitted to express the satisfaction with which the lecturers at this last-named institution can regard the result of ten years of teaching, during which period we owe it to the excellent character and industry of our students that a large number of them are now in highly responsible situations, both at home and in the colonies, acting as centres of scientific intelligence, and contributing far more than an average share to the increase of the material prosperity of the country.

Notwithstanding the very recent origin of mineralogy as a science, we cannot do better, in attempting to spread a taste for these studies, than bow to the precepts of our great renovator of physical science, Lord Bacon, who, with prophetic eye, saw in the distant future the triumph of the new philosophy of which he was the herald, though there were long weary years during which the seed lay invisible and apparently dormant in the ground before it could shoot up into a goodly tree. To sift and search into alleged facts, and to avoid the "apotheosis of error," is almost as needful as ever; and doubtless one of the very strongest arguments in favour of the introduction of this and other branches of natural history science into common education is the practice which they inculcate of exact observation. Nothing which we have it in our power to verify must be taken for granted. Truth is to be held as our authority, not authority as truth. "Lastly," says Bacon, "things of damaged credit which are yet current and oft repeated, some of them from carelessness, others from their use in metaphors, having lasted through many centuries (as, for example, that the diamond stops the action of the magnet, and that garlic weakens it, that amber attracts everything but the herb basil), these and many other such like it will be our duty not simply to reject in silence, but to proscribe in express words, to

“prevent their being any longer a nuisance to science.”\* I might occupy the whole of the time which remains to us with instances of inexact inquiry, or the want of the scientific method of observation, leading to lame and impotent conclusions, sometimes merely amusing, at others mischievous. Let me mention one or two as examples. When engaged, a few years ago, in examining the coal-measures of Colebrookdale, especially at certain works very near the river Severn, I became acquainted with the manager, in most respects a man of acuteness. Narrating his experiences, he informed me, that on several occasions he had found fossilized fishes in the coal. This would, in itself, have been a sufficient wonder. Further, that they were very like, in form and in the shape of their scales, to a fat Severn salmon. It was in vain that I remonstrated. They had, he said, been found several times, and such and such men could be called as witnesses. Further again, he added, when broken across, their flesh, although turned into stone, looked as pink and natural as if the fish were taken out of the river yesterday! The specimens had been given away, and it seemed difficult to decide what could be the grounds for so strange an assertion, when I fortunately halted with him beside a stack of recently raised ironstones. There, said he triumphantly, there is a piece of the fish; and the apotheosis of error was brought to an inglorious end by the evidence of the fragment itself, part of the scaly stem of a well-known coal plant fossilized in clay ironstone!

Again, there lately came for report to the Jermyn Street Museum a box covered with official seals, from an official board, which shall be nameless, containing a substance held, from the circumstances, to be of national value, and forwarded under attestations of officers who had given themselves not a little trouble in the matter. The first glimpse of an eye accustomed to observe showed that one after another of the senders had totally misconceived the contents, and had treated with the highest consideration an outcast among mineral species, common iron pyrites, the “corrupter” of ores as well as of coal, picked out and rejected as rubbish by half the miners in the world.

For the world at large we cannot afford to dis sever totally the higher aims of science from its economic bearings. The same great authority, in his *Novum Organum*, foresees that his new philosophy will not be widely palatable with the public. And as in those days there was no “royal road,” so we may be assured that in these there can be no “popular” one to true science, however readily some of its results may be accepted. “It does not,” says Bacon, “lie ready to hand; nor is it “to be picked up in passing; nor does it flatter the intellect by agreeing “with preconceived notions; nor will it descend to the capacity of the “vulgar except by its utility and effects.” The multitude, as Goethe has aphoristically remarked, when an observation or discovery is communicated, inquires what is the good of it; *cui bono* has, from the earliest times, been the cry of the ill-instructed; but they are not far wrong, for it is their only test of the value of a thing; and any course of instruction in the elements of the sciences must, I believe, and above all in this country, make some concessions to this feeling, or break down.

First of all, whether the instruction is to be detailed or to be elementary, let us have clear ideas of our subject and distinct terms to express them by. In other words, let us commence by agreeing on a series of definitions. For two of the more important divisions of mineralogy, crystalline form and chemical composition, these requisites have been already prepared. And let no one think to acquire or teach even the elements of mineralogy, without some previous acquaintance with geometry and with chemistry. A student should be prepared by a

\* Bacon, *Parasceve*, cap. viii.



sufficient familiarity with the first six and the eleventh book of Euclid, and even if he has not worked in a laboratory, at least with the principles of chemical science. That some few definitions should also be required proper to the special subject is natural, and the necessity for them is indicated by the looseness of terms often employed with respect to these matters in common language and even in books and legal business. Thus a mineral is properly described as a natural solid or liquid substance, of homogeneous and constant composition and not due to organic action. If we now take up a work in which, dealing as it does ably with the Laws of Mines and Minerals, the tyro would expect to find some precise and analogous statement of essential characters, we find that "a mineral has been defined to be a fossil, or what is dug out of the earth. The term may, however, in the most enlarged sense, be described as comprising every component part of the solid body of the earth, both external and internal, which is destitute of and incapable of supporting animal or vegetable life."\* It would be idle to show you how many substances not minerals at all are hereby included, and how grave questions might arise as to the exclusion of others which have an acknowledged right to be classed as true minerals. For want of a more general adoption of exactness, the "glorious uncertainty" of law is needlessly magnified, and frequent repetitions of those curious cases may be expected in which the grand question at issue is whether some particular substance is or is not, a mineral.

In the whole range of natural history there is perhaps nothing more beautiful and surprising, in our special subject nothing more worthy of the attention of thoughtful minds, than the forms in which minerals crystallize. To the common eye nothing more than pieces of brute matter, the crystals are to the educated understanding a convincing example of the harmony and order which pervade all nature. The atheist's "fortuitous concourse of atoms" becomes a laughing-stock to the crystallographer, and those wondrous figures mathematically regular amid seeming irregularity, and revealing under their numerous disguises unerring laws which link together groups of almost interminably varying forms, attest in all parts of the earth, in unmistakeable language, the unity of plan impressed on matter by the Great Designer.

Towards the end of the last century a system of crystallography was inaugurated by Romé de Lisle, Häuy, and Werner, in which the actual characters of forms were accurately traced, but which was based on a theory now no longer considered tenable. It may be specially mentioned because adopted by some of our own writers, especially Phillips, and Brooke, whose works are still in circulation. Among the various forms in which a given substance is found to crystallize, one of the simplest is selected as the *primitive* or *fundamental form*, from which all the others are to be deduced. Each crystal is held to be composed of *integral molecules*, of extreme minuteness, which are built up upon a regular plan. The shape of these molecules may or may not be the same as the primitive form with which the construction of the series of crystals is to begin. They are supposed to be so small as to be invisible even with the aid of the microscope, and thus might present their edges or angles where our eye sees only a plane surface. It is as when—to compare small things with great—we view the Great Pyramid from a distance, and imagine that its faces are smooth. A very near approach alone reveals the fact that these faces are formed of a series of steps presented by rectangular blocks. The addition to, or removal by decrement of these molecules from the primitive form, carried out in certain directions produces the derivative figures.

\* Bainbridge on the Law of Mines and Minerals, 1851.

The property of *cleavage*, or the tendency of minerals to split with bright surfaces in particular directions, was called in aid of Häuy's method. The form of the integrant molecules was determined by the cleavage of the mineral, and the primitive forms, although generally obtained by the same method, had in many cases, where cleavage was difficult or indistinct, to be suggested by probability. Further investigation revealed to Weiss of Berlin, that the principle really governing the apparently so variable groups of crystals is that of the fundamental relations of their dimensions. Hence it became convenient to refer their faces and angles to imaginary lines or directions within them, to which the term *axes* has been applied; and this method having been followed by subsequent authors, it may be mentioned that a full description will be found in Dana's Manual, and in Nicol's Elements of Mineralogy, as translated from the lucid work of Naumann of Leipzig, and in the compendious treatise of the Rev. W. Mitchell, published in 1856, in Orr's Circle of the Sciences.

The principles of Crystallography cannot as a general rule be advantageously studied from actual crystals. Within their unyielding laws of symmetry, they are subject to variations and irregularities which require much practice to make allowance for. Besides this the crystals of most minerals are expensive luxuries, beyond the reach of individuals and even of ordinary institutions. Drawings of the various forms are a great aid and excellent practice. But models offer, of all means, the most satisfactory assistance to the student, and I may recommend to your notice, for the preliminary teaching, glass models, such as those on the table, which exhibit with great distinctness the position of faces with respect to the axes of symmetry.\* Wooden models for the exemplification of the more composite forms may be had in great variety, and marked with the symbols proposed by various authors to represent the faces.† For self-instruction great advantage may be derived from modelling the forms in paper or card-board. The simplest and neatest method is to draw the faces on the flat surface so arranged that when some of the lines are cut partially through, and others entirely, the whole *net*, as it is termed, may be folded up into the required form.‡

It is hardly needful, in a brief review, to do more than allude to some of the phenomena which are intimately allied to crystallization, and in which experiment becomes a valuable ally. The cleavage of the commoner minerals should be frequently tested; that of many substances may be determined by mere inspection, from the included, perhaps only half expressed, planes of division, or from the soft and pearly lustre given off from faces parallel to which cleavage is very perfect. We must guard against the idea that the laminæ obtained by cleavage are those of structure, as relating to growth; contradictions and difficulties will otherwise soon arise. Take, for example, a cube of fluor spar; you will find within it cubical outlines indicated by different colours, one within the other, from which you might conclude that the growth had been effected by constant accretion parallel to the faces of the cube; yet search all the world, and you will never find a crystal of fluor which you can split parallel to those faces. Try the experiment on the solid angles, and the substance will divide with such constancy and regularity, giving you the thinnest, smoothest laminæ parallel to the eight planes of the octohedron, that you are now tempted to think that this other and just opposite arrangement must have been that by which the particles were

\* Made by Mr. Larkin of Brompton.

† Prepared by Mr. Larkin, with Dana's symbols: by Krantz of Bonn, a very full series, with Naumann's.

‡ Mr. Mitchell gives many of those crystal nets in his little treatise before referred to, and they are in a separate form to be had, as *Kopp's Krystallnetze*, through Messrs. Williams and Norgate, foreign booksellers.



regulated as they solidified. Truly, when we regard these ever-recurring forms, their angles all as mathematically true as if constructed by the most skilful instrument-maker, we cannot choose but think with the great Goethe—"Steine sind stumme lehrer."

See these inorganic particles, whether constituting mountain masses or grouping themselves in the atmosphere as crystals of snow, or lining with bright facets the mineral caverns deep in the crust of the earth, how they obey everywhere, independent of sunlight, or human notice, or admiration, the same rigid laws, and they seem to remind us of the weakness of that man who is often conceited enough to deem himself the centre of creation, and to make us contrast with his littleness the grandeur of those laws which we may attempt to read but not control!

Time would fail me were I to attempt to dwell at equal length on other means by which we must proceed systematically to consider the character of minerals. All the external properties may be readily dwelt upon and pointed out by teachers. In dealing with their composition, the blow-pipe, with a few re-agents, and the use of acids, ought to be familiar even to the learner. But I believe that nothing can so forcibly impress on the young mind all the peculiarities of character and grouping, no other method arouse so much interest in what might otherwise appear dry and repulsive, as the collecting of mineral specimens in their proper localities. Fortunate are those students to whom a burrow (the rubbish heap of a mine) or a metamorphic rock is accessible; but not the less important is it for those not equally favoured by their *locale* to visit the quarry, or the clay pit, or even the stone heap by the road-side, to hunt up some, at all events, of the varieties which may represent a species, and by actual observation to note some of those phenomena of occurrence which link our subject to geology, to chemistry, or to archæology, and thus prevent it from assuming the appearance of a mere list of names and qualities. One common substance thus thoroughly observed is worth a score of minerals read about in a handbook or talked over in a lecture. It is here that a teacher must exercise his judgment and test his real knowledge. Few can expect to be supplied with the fine collections which are indispensable to a full knowledge of the subject, and which from their costliness must necessarily be confined to a few large cities; but tact and perseverance may bring together at small expense a vast number of the more useful minerals, and it is in proportion to the commonness of the substance that we feel the importance of teaching something about it.

I cannot make an end of the subject in hand without saying a few words more on the application of mineralogy to the arts, and especially to mining, where it so frequently and variously comes into play. It has sometimes been urged that practical men need no scientific teaching of those matters among which they have been brought up and versed, for that they have the main facts already; and with a certain speciousness, for your shrewd copper miner, perhaps unable to read or write, will nevertheless be quick enough to detect the difference between the ores that are of value to him and other substances very like them; whilst the experienced tinner will probably excel many a mineralogist in judging of the appearances of a tin lode. But this is not enough for those that can learn more; it is a knowledge of certain facts, but not science. A foolish aquatic bird, in crossing a stream, will start on an oblique course, that is, will take advantage of the composition of forces; but the goose has not on that account a science of mechanics.

Let it be remembered, however, that the problems to be solved in this application are often very obscure or complicated, and that it needs years of observation and opportunities of visiting numerous mineral localities, to educate a man for such a service. A boon is to be obtained, and a great one, if only a larger number of moderately good observers be brought into the field; but I believe that it is very needful to be cautious

lest that knowledge which is capable of being converted into a good instrument be mistaken for the finished article. It is an easy thing to acquire the nomenclature and technical terms, and a certain acquaintance with the special facts as taught in text-books, but we must not confound this with the true feeling for science or the power of applying it. We may, and not rarely, see an aspirant to artistic fame, his locks long and flowing, his limbs encased in mediæval garb, wielding the painter's brush, and discoursing of art in a tongue unknown to the vulgar, and yet we well know that such externals will not make him a Raffaele or a Rubens, nay, rather that those very marks of outward resemblance are likely to be the index of great interior difference from the true feeling and force of the master.

Let teachers in schools and institutions be content, for the most part, to take up the science itself; let them do justice to that, and utility in practice will follow. What says, again, on this head the clear-sighted Bacon?

"For it is of the highest importance towards the progress of the sciences that the lecturers in each department should be chosen from the best and most instructed men, inasmuch as their work is not applied to a temporary use, but to the purpose of supplying the succession of science from age to age. This cannot be done unless such salaries and conditions are offered that each most eminent teacher may live content in his vocation, and that he may find nothing oppressive in remaining in his office, nor think of turning to practice. Wherefore that the sciences may flourish, the military law of David is to be observed, that 'the portion of him who went down to the battle and of him who remained with the baggage should be equal.' But for this the baggage would be badly looked after."—*Bacon de Augm.* lii.

Clearly, let us have the sciences spread as widely as possible, and let teachers take advantage of the liberal offers made to them with this end by the Council of Education. But let them take the matter conscientiously in hand; let them learn well and thoroughly what they have afterwards to teach; let them not pretend to be proficient in several different branches of science at once, lest their pupils should be brought to compare their case with that of the blind led by the blind. Let them also avoid the profession of applications to technical work for which they have not been duly prepared. We are sufficiently troubled in these latter days with pretenders; the nation has to suffer charlatans in art, charlatans in politics, charlatans in science. Let us hope that the crop may be kept down by a further spread of sound education, and that in this our special subject an increased attention to it may bring men's minds to a higher appreciation of the works of nature, and may, as assuredly would then follow, contribute in no small degree to the wealth and material comforts of the community.



LONDON :

For Her Majesty's Stationery Office.

Science and Art Department of the Committee of  
Council on Education.

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LECTURES  
ADDRESSED TO TEACHERS  
ON

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE VI.

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ON BOTANY;

DELIVERED AT  
THE SOUTH KENSINGTON MUSEUM,  
21st May 1860.

BY  
EDWIN LANKESTER, M.D., F.R.S.,

EXAMINER IN BOTANY, SCIENCE AND ART DEPARTMENT.



LONDON:

PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,  
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.

1860.

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*Price Twopence.*





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Council on Education.

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LECTURE VI.

ON BOTANY;

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21st May 1860.

BY

EDWIN LANKESTER, M.D., F.R.S.

DEAN OF THE BOTANICAL GARDEN AND ART DEPARTMENT.



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## LECTURE.

I HAVE been requested by the Committee of Council on Education to deliver a lecture on the best methods of acquiring and communicating a knowledge of botany. In attempting this task I shall only briefly allude to the importance of the Minute of Council on Education, by which examinations for schoolmasters in various branches of science have been instituted. It has for years been the reproach alike of our university and school system, that in the course of education pursued the various branches of knowledge comprehended under the name of the natural sciences are almost entirely ignored. These branches of science embrace the knowledge of all the great facts that have been established by the accurate observation of the properties and relations of the material world by which man is surrounded. The acquirement of the knowledge of these facts and the application of them to the production of the necessities, comforts, and luxuries of life, are the distinguishing features of modern European civilization. If we make a comparison between this civilization and that of ancient Greece and Rome, we shall find that its great features depend on the development of a knowledge of the forces and properties of matter as expressed in the sciences of mechanics and pneumatics, of the affinities of matter in chemistry, of its electrical properties, and the knowledge of the laws which regulate the life of animals and plants.

If, then, it can be shown that this civilization of ours secures a greater amount of happiness for the human race, if it secures a greater amount of physical development, a higher standard of moral action, a greater activity of the human intellect, and a loftier conception of the work and attributes of the great Creator, it surely needs no argument to show that the more widely we diffuse this knowledge, and the more broadly we lay its foundations, the better it must be for the human race.

It is not my place here to show you the relation of the various branches of natural science nor to point out how closely one is connected with the other; my duty now is, to show you the position of the science of botany, which comprehends the laws of the structure and life of plants, and to draw your attention to the best way of studying those laws and inculcating them on the mind of others.

Plants with animals form a great department of natural objects to which the term "organic" is employed, on account of the various organs which compose their entire structure. Both are distinguished from the mineral or inorganic world by certain common properties: thus their ultimate tissues are composed of cells; their outlines are curved, not straight as in the mineral world. Their forms are limited in size, and they are composed of a definite number of elements, in which carbon, hydrogen, nitrogen, and oxygen preponderate. They also possess life, by which we mean that they pass through a series of changes, many of which we know to be chemical and physical, which terminate in quiescence or death, but during this life new individuals are formed resembling those from which they originated. These are the principal points that distinguish plants and animals from minerals.

The distinction between plants and animals, though easily marked among the great groups of either kingdom is not easy amongst the



more minute and less developed forms. Hence the question what is an animal or a plant? is one that cannot at the present day be solved either theoretically or practically. Without attempting to discuss the question I would give the following distinctions by way of assisting you in the further study of this subject:—

1. Plants derive their nourishment from mineral or inorganic substances, animals from organized matters.
2. Plants absorb their nutriment to a greater or lesser extent by their whole external surface, whilst animals possess a mouth, and take up their nutriment from an internal bag or stomach.
3. Plants are mostly fixed, whilst animals have a power of moving about. To this distinction, however, there are numerous exceptions.
4. The tissues of plants are distinguished by the tendency to absorb carbonic acid and throw off oxygen, whilst those of animals absorb oxygen and throw off carbonic acid gas.
5. Both plants and animals are developed from an impressible and motile protoplasm, but in animals this substance becomes differentiated into nerves and muscles.

The question then to which I would now address myself is how to study these organisms which we call plants. The division of the subject which I have always pursued in teaching, and which I think is the best, is as follows:—

1. The Chemistry of plants, embracing so much of the chemistry of the elements of plants as is involved in the changes which their elements undergo during the life of plants.
2. The Histology of plants, comprehending a knowledge of the origin, form, and development of the ultimate cells or parts of which the tissues of plants are composed.
3. The Morphology of plants, embracing a knowledge of the structure of each organ, and the laws of its development.
4. The Physiology of plants, comprising a knowledge of the functions which the plant as a whole and its organs perform.
5. The Classification of plants, comprehending their arrangement into classes, orders, genera and species, according to their likeness and unlikeness the one to the other.

Beginning then with the Chemistry we come to the question, how best to learn or to teach this branch of our subject. In the first place then I would say that this is not to be done by books alone. There are about sixteen elements found in the vegetable kingdom, nearly the same as those in the animal kingdom. These elements in their pure form should be exhibited to the student, and their properties explained. They may be divided into two groups, the *organic* and the *inorganic*. The first comprising those which are universally present, and these are carbon, hydrogen, oxygen and nitrogen. The second group is not so universally present, and never in so large quantities as the first; it includes sulphur, phosphorus, chlorine, iodine, bromine, fluorine, silicon, sodium, potassium, calcium, magnesium and iron. The compounds of these latter groups which are found in plants should be exhibited, and their influence on the life of plants explained. Thus chlorine and sodium form common salt, which determines to a great extent the vegetation of the sea and of the sea shore. Again phosphorus combines with oxygen and forms phosphoric acid, which combines with the alkalis and earths, especially lime, forming phosphates and these substances are so necessary to the growth of plants used by man that they are supplied artificially as manures to the soil. Certain plants as the microscopic diatomaceae, the horsetails, the grasses and the palms, require large quantities of silica for their growth, and perish where this substance is absent.



The organic group of elements is, however, the most important, and the student should be made thoroughly to understand the properties of carbon, hydrogen, oxygen, and nitrogen. The compounds of these substances through which plants are nourished should be studied, as water, carbonic acid, ammonia, and nitric acid. The influence of these agents may be demonstrated by experiments on living plants. A small garden, or even boxes containing soil, in the hands of a skilful teacher, would serve to demonstrate the action of these agents on the life of plants. The quantity of water in plants may be demonstrated by weighing plants before and after drying. A plant may be burned in a crucible and its indestructible ashes exhibited. The plant may be decomposed and the presence of carbonic acid gas and ammonia demonstrated.

From these general facts the student may be led to consider the compounds formed by the four organic elements in the tissues of plants. Here we have two sets of compounds; the first used is the nutrition of the plant, and generally present in all plants; and the second set comprising substances peculiar to certain plants or parts of plants, but not essential to their nutrition.

To the first group belong the compounds cellulose or lignine, starch, sugar, grape sugar, fixed oils, albumen, fibrine, caseine. Each of these substances should be shown to the pupil, separated from the plant, and also as it exists in the tissues of the plant, and its physical and chemical properties demonstrated. Take starch as an example. Its diffusibility and insolubility in water should be shown; also its property of mixing and gelatinising with water at a high temperature. The action of iodine on it should be explained, and sections of the tissues of plants containing various forms of starch should be exhibited under the microscope.

It would be impossible to enter comprehensively into the compounds of the organic elements which form the secretions of plants, but certain groups may be easily illustrated. Thus the various colouring matters, including chlorophyle, may be studied. The action of acids and alkalies on litmus or red and blue colouring matters may be explained and illustrated. The relation of these substances to the arts of dyeing and calico printing should also be brought before the pupil, and some easily-understood illustrations given.

In the same way the groups of vegetable acids, volatile oils, alkaloids, resins, and hydro-carbons may be treated. A collection of these substances should be made by the teacher, and, where possible, the living plants producing these secretions should be exhibited to the pupil.

Such instruction will prepare the pupil for entering on the study of the tissues which are formed out of the foregoing elements and compounds with the greatest success. In studying the Histology of plants, the microscope is essential. The science of histology depends mainly on this instrument. When possible, each student should be supplied with a lens, an instrument which is now sold very cheap. At any rate, the teacher cannot dispense with a microscope. A compound achromatic instrument should be preferred, and these may now be purchased from thirty shillings and upwards. Sections of various parts of plants should be made, and the pupil's attention directed to the cellular and vascular tissues; to the origin of the tissues in the cytoblast or primordial utricle; to the markings on the cells and vessels, and to the general distribution of these elementary parts in the various organs of the plant. Drawings, engravings, and diagrams may be made use of, but only as a means of assisting direct observations on the tissues as they exist in the living plant.

In the examination of the tissues of plants, there are a large number of practical points that should not be lost sight of. The structure of the cells in such substances as cork and the ivory nut may be examined,



and the practical purposes to which they are applied shown to be dependent on the structure and arrangement of the cells. The relation between the forms of such cells as those which exist in the ivory nut and those of the hard parts of animals should be pointed out.

The whole subject of the structure of the hairs of plants is full of interest, but it gains a practical interest of the highest kind when it is found that the peculiar conformation of the cotton hair is the source of its cohesive and weaving properties by which it contributes so largely to our national wealth.

The vascular tissues of plants may be examined from the same point of view. The woody tissue of the flax, the hemp, the New Zealand flax, jute, and a number of other plants are employed for making textile fabrics of various kinds. Each tissue has its own peculiar characters, which can only be detected by the aid of the microscope and the use of this instrument in making out the structure of fabrics should be explained. So also with the adulteration of articles of food. Many of these are easily detected by the aid which the microscope affords in unravelling the tissues of articles surreptitiously introduced for the purposes of fraud. These hints will be sufficient to show you how practical this apparently recondite department of botanical study may be made.

I now come to consider the subject of the Morphology of plants, which comprehends the study of the structure of individual organs and the modifications they undergo in the various forms of plants.

As a matter of course, before speaking of the modifications of organs, the pupil should be thoroughly instructed in the nature of the various organs, and be able to recognize them at a glance in all the more common forms of plants. For the purposes of instruction a variety of plants should be gathered from the fields taken up by the root. The general structure of a plant should first be described, beginning with the root and passing on to the stem. The stem should be carefully dissected, and each pupil should have specimens placed in his hands to follow the teacher in those demonstrations. When the stem has been mastered the teacher should proceed to examine before his pupils leaves, stipules, bracts, calyx, corolla, stamens and pistil till every pupil has a distinct impression of the nature of a flowering plant at least. The flowerless plants, however, have a high interest, and where the teacher is well versed in their structure he may easily compare their organs with those of flowering plants.

When the differences of the various organs are well understood, the attention of the pupil may be drawn to some of the general facts in the structure of plants. There is no one more calculated to produce an impression and to bear fruit than the general fact that all parts of a plant are referable to changes in the leaf or the stem.

Without at all endeavouring to inculcate upon the mind of the student the doctrine of archetypes in nature, the simple plan of a plant such as is given in Schleiden's "Plant a Biography" may be exhibited with advantage to the student. He will then see that every organ is represented as being a modification of stem or leaf. In order to impress this general law on the mind a variety of plants should be presented to the student in various stages of growth. Flowers and fruit are especially complicated in some plants, and the student should be encouraged to point out what he regards as stem structures and what as leaf structures.

As a subordinate morphological law, I would point to the general fact that leaves assume their various forms according to the relative growth of the vascular and cellular tissues. At almost all seasons of the year, leaves enough to illustrate this fact may be found. The spines of the furze and the barberry, the cut leaves of the Umbelliferae, the entire leaves of the cabbage, the serrated leaves of the dandelion, and the



succulent leaves of the house-leek, are some of the examples which might be produced to impress this law.

Very striking are the laws relating to numbers. The prevalence of the number three in the flowering organs of one large class of plants, and of the numbers four and five in another class, are facts that the youngest pupil can be easily made to understand. The prevalence of the numbers four and five in great groups of the last class can be easily demonstrated from common plants around us, as the prevalence of four in the order Onagraceæ, and half four in the order Oleaceæ. The occasional departure in one series of organs from the prevailing number should also be pointed out, as the four stamens in the Scrophulariaceæ and Lamiaceæ, when all other parts of the flower are five, and of six stamens in the Cruciferae, when all other parts of the flower are arranged on the number four.

I give these as common examples, and of plants which grow wild in our own country. The teacher who wishes to pursue this subject will find in such a work as Schleiden's "Principles of Scientific Botany" ample illustrations to guide him in his selection of further examples. There is one department of this subject the importance of which in the study of plants can hardly be overrated, and that is the history of the development of the plant and its parts. Each plant has a history, and its parts assume at different stages of its growth different aspects. Let me illustrate this subject by the history of an acorn. Taking an acorn, you might think it was a superior fruit sitting in an inferior calyx. You might even suppose that the fruit had been surrounded by stamens and a corolla. But if you examine the flowers of the oak in the early stages of their growth, you will find that it is a monœcious plant, that the stamens and pistils are seated on different flower-stalks, and that the stamens are attached to an elongated catkin, altogether differing in form from the flower which bears the pistils. If you ever look for these flowers, you will find the pistil seated in the midst of a number of scales, which form an involucre. Open the pistil, and you discover three cells, and in each cell two ovules. Now, it is this involucre which becomes the cup, and gradually one out of the six ovules presses on its fellow ovules on all sides, and squeezes them and the cells which they occupy out of existence, and forms the one-seeded inferior fruit which the acorn really is. In the sweet chestnut and the beech the involucre which forms a cup in the acorn, completely closes over the seed, and forms the outside or shell of the fruit. You see in this case how necessary it is to observe the development, or we should know little or nothing of the true relationship of these fruits and plants the one to the other.

There are many other equally striking cases of the necessity of studying the developmental history of parts of plants, but this must suffice as an illustration.

From the study of the laws of form in plants we may proceed to Vegetable Physiology, the study of their functions. Whilst growth is going on, and each organ is assuming a definite form according to fixed laws, the matter of which they are composed is undergoing continual changes. Like the higher organisms of the animal kingdom, plants take up food from without by the agency of their roots and surface. After the food has been absorbed it is carried into the interior of the tissues of which the plant is composed, and there it is changed by powerful chemical forces brought into action by the agency of heat and light. Water, carbonic acid, and ammonia, are changed into cellulose, starch, sugar, oil, protein and the other secretions of plants. During these changes water passes off from the plant in large quantities, also oxygen gas. The functions of nutrition and excretion are thus carried on. The whole plant or parts of the plant go on increasing till they



have attained their definite forms. In one set of cells or tissues these processes come to an end; the whole plant or parts of the plant, as the leaves, die. In some parts, however, an arrest of growth takes place without death. The organs in which this takes place are known as buds or seeds, according as cells of the same kind or of two different kinds assume this suspended condition.

I have here sketched the life-history of the plant, the principal facts of which may be brought under the observation of the pupil. In the study of the chemistry of plants he will have learned the nature of the food of plants. He may now be taught the relation of the plant to the soil. The absorbing properties of the various substances, as sand, limestone, sandstone, clay, and humus entering into the composition of soil may be made the subject of experiment. Where a garden is not at hand, boxes or pots containing these soils may be planted with the same plant in order to show their effect. The influence of the nitrates, the salts of ammonia and of phosphates may be also thus exhibited. The action of light and heat on the growth of plants may be also demonstrated in the same way. Experiments may be so arranged that the student may be able to distinguish between the effects of light and heat. Here too a knowledge of facts borrowed from other departments of science should be impressed on the mind of the pupil. The action of light upon plants in causing the decomposition of carbonic acid is probably identical with the influence it exerts upon the chlorides and iodides of silver in the art of photography.

Again with regard to heat, its greatest influence on plants is owing to its converting water into vapour. Plants are constantly exhaling water under this influence. In this way the absorptive function of the root is maintained, and plants appropriate organic and inorganic matters according to the quantity of water exhaled.

Again the function of absorption in plants is closely connected with the purely physical phenomenon of capillary attraction, endosmose and exosmose, and the diffusion of gases, and experiments may be easily devised to illustrate these phenomena.

In directing attention to the phenomena of impregnation in plants the microscope should be used, and the structure of the pollen grains, and the ovules and the production of the pollen tube should be thus demonstrated.

When the student has gone through these subjects, he will be prepared to enter upon the study of Systematic Botany or the arrangement of plants into classes, orders, genera and species. In the teaching this department I think it is most convenient to direct attention to British wild plants; both on account of the plants themselves being less liable to change, and because inexpensive books with descriptions sufficiently extended may be employed. I recommend for this purpose either Babington's Manual of British Botany, or Bentham's Handbook of the British Flora. Other books on British botany however may be employed.

In the first place, the structure of the great classes of flowering and flowerless plants should be understood; then their great subdivisions. Thus, for instance, the structure of the great subdivisions of the class of Exogens, Thalamifloræ, Calycifloræ, Corollifloræ and Monochlamydeæ should be impressed upon the mind: after this the orders in any of these subdivisions may be taken up. I do not recommend that any particular sequence of these orders should be pursued. This must depend, in a great measure, upon the season of the year, and the facility of getting access to plants. At any rate the pupil should always have the illustrative specimens in his hand. I have found it a good plan to take the plant and write down on a board, with chalk, all the distinguishing features of the plant, as far as the order is concerned, beginning with the

stem and passing on to the leaves and the parts of the flower. After a few orders have thus been gone over, the teacher may then draw the attention of his pupils to the point or points of structure in which it differs from all other orders, and to the points of structure in which it agrees with allied orders.

Let me give you an example. Suppose you have specimens of the four Monopetalous orders, Scrophulariaceæ, Boraginaceæ, Lamiaceæ, and Solanaceæ, you go over the principal points of structure in each specimen; you may then draw the attention of your class to the combined characters that distinguish Scrophulariaceæ from the other three. Its irregular flowers, didynamous stamens, and two-celled pistils or capsules. It agrees, however, with Lamiaceæ in its irregular flowers, and with Solanaceæ in its two-celled fruit; but it differs from Lamiaceæ and Boraginaceæ in its two-celled fruit, and from Solanaceæ and Boraginaceæ in its irregular flowers. Such comparisons serve to impress points of structure on the mind of the pupil. When a number of orders have been thus gone through, the pupil should be taught to analyse them for himself upon the plan of a dichotomous division, such as has been introduced by Dr. Lindley into his works on systematic botany, and followed by Mr. Bentham in his hand-book. Thus, taking the four orders above named, we may arrange them in the following ways:—

Flowers irregular:

Fruit, two-celled, Scrophulariaceæ.

Fruit, four-nutted, Lamiaceæ.

Flowers regular,

Fruit, two-celled, Solanaceæ.

Fruit, four-nutted, Boraginaceæ.

Or, we may make the stamens the basis of our distinction:

Stamens pentandrous:

Fruit, four-nutted, Boraginaceæ.

Fruit, two-celled, Solanaceæ.

Stamens didynamous:

Fruit, four-nutted, Lamiaceæ.

Fruit, two-celled, Scrophulariaceæ.

Or, we may make the fruit our first distinction:

Fruit two-celled,

Flowers, regular, Solanaceæ.

Flowers, irregular, Scrophulariaceæ.

Fruit four-nutted:

Flowers, regular, Boraginaceæ.

Flowers, irregular, Lamiaceæ.

The pupil should be encouraged to draw up such analyses of the orders he has studied, and in the course of a little time he will be enabled to distinguish the principal orders of British flowering plants.

Several orders having been mastered, the pupil may now be encouraged to make out genera and species. Genera are groups subordinate to orders, and embrace one or more species, according to the characters which they possess. The genus may be looked upon as a means of grouping the species which are the ultimate forms which a group of animals or plants are supposed to assume. A species is a collection of individuals which resemble each other more than they resemble anything else. Without entering into any question as to the origin of species or the kind of characters that ought to distinguish them, I would remind you that certain forms of plants are thus recognised by all writers on botany. It will now become the task of the student to recognise these species. For this purpose he may be taken



into the fields, and plants collected and brought home for the purpose of naming, by the aid of the manuals of which I have spoken. Having found the order and the genus, he goes on to seek the species, and this he should be encouraged to do by the aid of the manual alone. When he is enabled to distinguish species he will have attained one great object of systematic Botany.

I would, however, further recommend, where it can be done, that the pupil be encouraged, after naming his plant, to dry it and put it down for the purpose of forming an herbarium or hortus siccus. Such a procedure is a great stimulus to the collecting and naming plants, and every one will feel a kind of pride in thus accumulating in a form in which they can always be consulted, the plants which they have picked up in their various country excursions. All the little practical details connected with this subject are admirably illustrated in the Educational Department of this Museum, by the exhibition of apparatus and specimens from the National School at Hitcham, in Suffolk. The study of botany has been introduced amongst the girls in this school, by the Rev. Professor Henslow with the greatest success. He has not only demonstrated that botany may be taught with success to village children, but that its introduction has had a beneficial influence on all the other branches of education carried on in the school.

I have now finished what I have to say on the subject of learning and teaching botany, and I might perhaps conclude with a few remarks recommendatory of this branch of study. I feel, however, that this is unnecessary, as you must feel from the facts I have placed before you, that the study of plants, both practically and educationally, must be attended with great advantages.

To those who are anxious to study the great laws of life, by which the higher forms of organic beings exist, a knowledge of the laws of the life of plants is almost essential, as they present simpler forms of organic existence than are found in the animal world.

Practically, the vegetable kingdom demands accurate study, as it is the great source of power in animal life. Without plants the animal machine could not be worked. It is by undoing the chemistry of the plant, liberating the forces employed in forming the vegetable compounds used by animals as food, that heat, the muscular power and the nervous sensibility of the animal, are maintained. The greatest problems of human existence lie within the limits of this inquiry, and all human power, and thought, and hope, and progress, result from the transference of the forces treasured up in plants to the organisation of man.

Descending lower in our view of the relation of the vegetable kingdom we find man dependent upon it for a vast amount of the materials of his use, comfort, and luxury, in his daily life. He is clothed with the fibres of cotton and flax, he is adorned with the colours of the indigo, madder, and a hundred other plants, the canvass he spreads to waft him over the ocean is hemp, he lives in houses built largely of wood, and in which almost every article of use is of the same material, his iron rails are laid on wooden sleepers, his ships are built of timber, the great agent of his progress is the dried pulp of plants, which forms paper, in short, from his willow cradle to his oaken coffin, man is more or less dependent upon the structure and properties of plants for his work and comfort in life.

But these considerations may fail to impress those to whom my lecture is addressed, that botany should constitute a necessary part of a systematic course of education. There are, however, special reasons why botany amongst the natural history sciences should be preferred in a course of instruction intended for the development of the reason and observing powers. These reasons have been put forward by an authority whose ability to give an opinion on the subject no one can doubt, and

Boyd

whose position in the University of Cambridge would be the guarantee that he was influenced by no wish to interfere with courses of instruction already recognised. Dr. Whewell, the Master of Trinity, in his work "Of a liberal education," says, "I have already remarked elsewhere, that among the sciences, natural history affords very valuable lessons which may beneficially be made a portion of education: the more so, inasmuch as this study may serve to correct prejudices and mental habits which have often been cherished by making pure mathematics the main instrument of education. The study of natural history teaches the student that there may be an exact use of names and an accumulated store of indisputable truths on a subject in which names are not appropriated by definitions, but by the condition that they shall serve for the expression of truth. These sciences show also that there may exist a system of descriptive terms which shall convey a conception of objects almost as distinct as the senses themselves can acquire for us; at least, when the senses have been educated to respond to such a terminology. *Botany in particular is a beautiful and almost perfect example of these scientific merits,* and an acquaintance with the philosophy of botany will supply the student with a portion of the philosophy of the progressive sciences, highly important, but for the most part hitherto omitted in the usual plans of a liberal education. But the philosophy of botany cannot be really understood without an acquaintance with a considerable portion, at least, of the details of systematic botany. On these grounds I should much desire to see botany, or some other branch of natural history, or natural history in general introduced as a common element into our higher education, and recommended to the study of those who desire to have any clear view of the progressive sciences, since it is in fact the key and ground-work of a large portion of those sciences."

I need not add that I entirely concur in these remarks, and that I believe that what applies to the higher education of our universities is equally applicable to the lower education of our middle class, and working class schools. Nay, more, if in the one case it is necessary in order to give an intelligent apprehension of the real progress of human intellect, in the other case it is more necessary in order to give precision and intelligence to the efforts of those the success of whose daily pursuits is dependent on the skilful adaptation and direction of the laws and properties of the material world.

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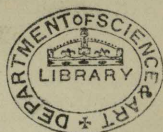




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Science and Art Department of the Committee of  
Council on Education.

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# LECTURES

ADDRESSED TO TEACHERS

ON

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE

METHOD OF TEACHING A SCIENCE CLASS.

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## LECTURE VII.

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ON THE IMPORTANCE OF THE STUDY OF  
CHEMISTRY ;

DELIVERED AT

THE SOUTH KENSINGTON MUSEUM,  
7th January 1861,

BY

A. W. HOFMANN, LL.D., F.R.S.



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## LECTURE.

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IN compliance with an invitation from the Committee of Council on Education, I will endeavour to bring under your notice some considerations on the Study of Chemistry as part in a well arranged system of mental cultivation. In an attempt of this kind, owing to the endless variety of relations which chemistry bears to other branches of knowledge, so many starting points present themselves, that it seems important to define at the very outset the aspects under which I propose to submit the subject to your attention. I may therefore state at once that I shall examine the question more especially in two directions, aiming, in this first lecture, at giving you a survey of the conditions which render the study of chemistry invaluable as advancing the material well-being and the intellectual progress of mankind, and pointing out in a second lecture, the path recognized by experience as the shortest and safest towards the perfect mastery of chemistry as a science; adding at the same time, some remarks on the chemical instruction in schools, where chemistry is taught as a branch of general education, and as a means of mental training.

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The importance of the study of the natural sciences, and particularly of chemistry, becomes at once obvious when we compare our modern civilization with that of antiquity. Losing sight of the revolution brought about in the human mind by the reception of new religious views, as not immediately connected with the subject of this discourse, it cannot be denied that all the other steps of progress which modern times have made, are exclusively derived from the ardent cultivation of the study of nature.

In poetry and sculpture the ancients are still unsurpassed. What epic poem, as to originality, vigour, and freshness, can be compared to those of Homer? We admire the genius of a Shakespeare, the searching eye with which he traces human nature to her innermost recesses; we are carried away by his life-warm creations. Whether he reveal the tenderest emotions of the human breast, or roll before our view the stormy waves of passion, we unhesitatingly accord to him the palm as the first dramatic poet of modern times. Let those, however, who have read the Greek tragedians say, whether Sophocles has been surpassed by Shakespeare!—Modern sculpture ever turns to the antique as to a model of unattained perfection. In all times, from all countries, the sculptor has made his pilgrimage to Rome and Greece to study in the school of the ancients.

He who has seen the frescoes on the walls of Pompeii will bear witness to the high attainments of the painters of those ages, and, granting a great development to the art of painting in modern times, it would be difficult to say how far this is owing to our different mode of viewing the world, which has altogether changed the scope of artistic aspiration, or to the technical improvements, more especially in the colours, which are at present at the disposal of the painter. It is next to impossible to form a clear notion of the music of the ancients;



but, if we consider the simplicity of the instruments at their command, there can be no doubt that the advance, which modern music has made, is mainly referable to our perfected construction of their instruments and to the invention of new instruments, for which again we are indebted to an active study of the laws of nature.

Our writers of history, too, in what do they surpass their predecessors except in the endless abundance of material which century after century has heaped up in addition to what they possessed? The writings of the ancient historians are still the first which we place in the hands of our youth, and experience has proved what an inexhaustible source of mental and moral culture successive generations have found in these works. No nation of modern times has produced more brilliant orators than England; as none possesses freer institutions, the native soil of eloquence. But have modern orators outstripped the Greeks and Romans (except, perhaps, in the formidable length of their speeches)? To him who would ascertain what progress the schools of mental philosophy in later times have made, compared with those of antiquity, I recommend a plunge into the works with which a certain school deluged the literature of Germany at the commencement of this century. Again, has not modern jurisprudence its very root in the Roman law? Is not the Roman law taught at this very day in all the continental universities? and is not the civil law of the Romans still in force in many states at the present time? I may be reminded of the enormous strides which the mathematical sciences have made in modern times, but we still learn from Euclid the rudiments of geometry: and are we quite sure that the methods, which, like so much new apparatus, has been supplied to mathematical operations, would have unfolded themselves, had it not been for the wonderful development of the natural sciences, more especially of physics, which continually offered to mathematical treatment new material to be mastered, and thus in a measure involved the creation of these very methods?

I might easily pursue this parallel still farther, but I have already said enough for my purpose.\* Modern civilization most undoubtedly has its footing in the zealous investigation which the present age has devoted to the forces of nature, and in the wonderful results to which this investigation has led, and, day by day, is leading. The study of the forces of nature has subjected them to our will. Knowledge is power; under no conditions is this axiom truer than when applied to the knowledge of natural phenomena. Time and trouble spent on the study of nature is amply repaid, for in every well examined physical force, man educates for himself an obedient servant, ready at all times to fulfil his behests.

What giant strides in all directions have been made in consequence of the development of the various branches of physical knowledge? The power of steam has gradually become subservient to such a variety of uses that we can scarcely imagine our existence without it; and yet when we see our steamships cleaving the ocean from hemisphere to hemisphere, or the locomotive engine rushing with the speed of the storm over the country, how rarely does it occur to us that we are indebted for this rich inheritance to the patient study of the laws of *heat*? Were I to pursue, into its various directions, the influence which the substitution of steam power for the uncertain forces of water and wind, or for animal force, has exerted on the several arts and manufactures, I should exceed the limits of this

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\* The subject has been very fully treated by Prof. Pettenkofer in one of his popular lectures. In the same lecture the author lucidly explains the causes which, in antiquity, prevented the free development of the study of nature.



sketch ; but I am tempted to glance for a moment at the wonderful change which the introduction of steam has produced in the civilization of nations. We are still far distant from the reign of uninterrupted peace ; the clang of arms no sooner ceases in one country, than the flames of war are seen raging in another, but how different in form and fashion are our wars from those of antiquity ! We still wage war, but no longer for the purpose of enslaving entire nations. We need no slaves, steam engines are our slaves, our helots. The constructions of our architects, and of our engineers, are not less grand than the pyramids of ancient Egypt, whilst they are immeasurably more useful ; but no longer are the inhabitants of whole provinces made to groan for years like beasts of burden, no longer is the towering pile cemented by the sweat of an enslaved people.

A harvest of results, not less unexpected, has rewarded the inquiries in *electricity*, a science of which antiquity had not even an anticipation. A century has not passed since Franklin made his experiments with the electric kite ; a shorter time still has elapsed since Galvani saw the frog's leg quiver on the balcony at Bologna, and scarcely have the inquiries been completed which place in its true light the connexion between the experiments of both observers ; but what incalculable advantage has not the human race already reaped from these observations ! Everyone knows that Franklin was led by the prosecution of his experiments, to the invention of the lightning conductor, and that the elaboration of Galvani's observations gave rise to the construction, in the hands of Volta, of his battery, that grand lever of our own times. A faithful handmaid, the voltaic battery multiplies for us, in durable metal, the noblest productions of artistic genius, formerly accessible only to the chosen few, and this with an accuracy of which no other mode is capable. Not satisfied with giving an exact copy of the form, it clothes the copper with a layer of silver or gold, almost imponderable, yet sufficiently close and uniform to protect the delicate surface against the tooth of time. Beaming from the lofty pharus, the electric ray warns the seaman from the treacherous rock, and guides him safely into port. As a winged messenger, lastly, annihilating time and space, the electric current bears our thoughts with the rapidity of their conception over land and under sea. Great as these acquisitions are, the list of benefits which our generation is destined to reap from the study of electricity is not yet concluded. It was by the help of the voltaic battery that Davy, at the commencement of this century, was enabled to decompose the alkalis into their elements. The isolation of the alkali-metals has at all times been considered one of the finest achievements of chemistry. During the half century that has since elapsed, it has afforded incalculable aid to the progress of science ; but it was reserved for our time to hail on the market-place of life this glorious discovery of Davy. By the help of one of the metals discovered by Davy,—by the help of sodium,—chemists had succeeded in separating from common clay a metal, equally distinguished for its peculiar white lustre, its lightness, and its resistance to the atmosphere. The industrial production of aluminium, which is of unlimited occurrence in nature, had been impeded hitherto by the high price of the sodium necessary in its extraction. By the unremitting efforts, however, of H. Ste. Claire Deville, the preparation of sodium has lately become so simplified and so cheapened, that the manufacture of aluminium on a large scale has been actively carried on for some time ; and thus we owe to the combined inquiries of chemistry and physics, an industry, the future of which it would be difficult at this moment to calculate.



Scarcely less rich and interesting are the acquisitions which modern times have derived from the assiduous inquiries into the nature of *light*. To the comprehension of its laws, we are indebted for the perfection of the instruments, which, embracing as it were the infinite in both directions, have gathered the vastness of the heavens within the sphere of our perception, and expanded to our view the living world in the water drop. The phenomena of polarization, but a few years ago the exclusive property of abstract science, have taken their place among the adaptations of optics to practical life. Aided by the polarizing prism, the navigator may search the seas for the shoals threatening his destruction, and the fisherman follow the movements of his prey through depths impenetrable to his unaided eye. In the hands of a Biot, a ray of polarized light became, to the sugar manufacturer, an index of the amount of saccharine matter contained in his liquors; whilst directed by the genius of a Wheatstone, we have seen it performing the work of a chronometer. (Playfair.\*)

The method of fixing the picture of the camera obscura, that marvel in the history of science, placed, as it were, on the boundary line between optics and chemistry, directs our consideration more especially to the fruits reaped from *chemical inquiry*.† The study of the solar ray led the way to the contrivance of an instrument, which, imitating the structure of the human eye, presents within a narrow compass a faithful copy of the grandest scenes and of the most fragmentary miniatures of nature and art. To this picture, the fugitive offspring of a passing ray, chemical science has given permanent life. But before this discovery, which is one of the most graceful achievements of our own times, could be accomplished, what thought, what toil was necessary, what a series of researches were required, perfectly unconnected with the final result, which nobody could have anticipated. The ley of the soap-boiler had to give up its iodine: the properties of this new element, and its action on various other substances had to be carefully studied; the investigation of sulphur and its oxides had to teach us the existence and the properties of hyposulphurous acid; gun-cotton, lastly, of ephemeral celebrity whilst threatening the world with destruction, had to be tamed down to the permanent usefulness which it possesses in the form of collodion.

Photography is not the only fruit which has arisen from the union of optics and chemistry. The last few months have given evidence of the treasures which are still to be raised on the boundary domains of the two sciences.

It is well known that the spectrum of a flame, of a gas-flame for instance, in which certain substances are volatilized, exhibits peculiar bright lines, the colour and position of which varies according to the nature of the substance. These phenomena, investigated by several observers, and more especially by Plücker, have lately been further pursued by Kirchhoff and Bunsen. Their experiments have led to truly astonishing results. Not only have these philosophers been enabled to endow science with perfectly new methods of research, in comparison with which the ordinary modes of analysis are coarse and clumsy; but the delicacy of their process has permitted them to

\* The Study of abstract Science essential to the Progress of Industry. Records of the School of Mines, part I., 1852.

† Some years ago I delivered a lecture on the Importance of the Study of Experimental Science, in a national point of view, at one of the evening meetings of the Royal College of Chemistry. Several of the illustrations given in the text are quoted from this lecture, which was never published, although a small number of copies were circulated among the Members of the College.



recognize the existence of new elementary substances, which, like satellites, accompany the commoner elements. Within the last few weeks they have announced the discovery of a new metal, very similar to potassium, for which they have proposed the name of cæsius, from the Latin word *cæsius*, expressing the peculiar greyish blue colour of the spectrum line, the observation of which gave rise to this remarkable discovery.

I have in the first place directed your attention to the achievements which chemistry has accomplished in conjunction with her older sister, Physics. Many of the phenomena which constitute the domain of chemistry, have been known for centuries; but it is only in modern times that this knowledge has been raised to the rank of an independent science. Little more than half a century has elapsed since chemical knowledge became chemical science, yet how manifold are the services which this new science has rendered in so short a period! It was in the latter half of the last century that the combined activity of some of the rarest minds working in various countries began to spread light over this field of knowledge. The genius and laborious researches of a Black, a Priestley, a Watt, a Cavendish in this country, of a Lavoisier in France, and a Scheele in Sweden laid the foundations of the grand edifice which has since been raised by the united labours of scientific chemists throughout the world; they were the workers out of the principles of that enlightened method of interrogating nature, the introduction of which into the arts and manufactures has effected more in the brief space of fifty years, than the unmethodical experiments of many previous centuries had achieved. The "transmutation of metals," and the "*elixir vitae*," which had eluded the ardour and the perseverance of the alchemist, became the legacy of the scientific chemist, who searched for the philosopher's stone, not in sowing the metals, not in the fragrance of flowers, or in the brilliancy of the morning dew, but in the faithful study of nature's phenomena, and in the investigation of her laws throughout creation. Modern chemistry has not attempted to convert lead into gold, but what immense sources of individual and national wealth have been opened since the adoption of its methods has infused new life into every branch of industry! On comparing the acquirements of the present age, our comforts, our sanitary regulations, our means of communication, &c., with the state of things in the last century, it may with truth be said that human life has actually gained in duration, while its enjoyments have been increased a thousand fold. It would be both interesting and useful, did this brief sketch admit of it, to notice the effects of chemical knowledge on the various branches of industry in every department of life. It would be found, that not only every art and every trade, but that every individual had profited by the labours of the chemist.

In taking a retrospect of the rapid progress which some of the arts and manufactures, depending upon chemistry, have made in modern times, we are at a loss to know where to begin our survey, every branch of industry could furnish the most brilliant illustrations.

Were I to trace with you the history of *sulphuric acid*, from the moment when the Erfurt monastery first witnessed oil of vitriol passing over, drop by drop, from the alembic of Basilius Valentinus, up to the present time, when hundreds of thousands of tons are sent forth from the colossal lead-chambers of Great Britain alone; were I to enlarge on the influence which chemistry, by raising



the production of sulphuric acid to its present degree of perfection, has exerted on the development of chemical manufactures; were I to describe the action of sulphuric acid in the preparation of the other acids, of nitric, hydrochloric, of acetic acid; its application in the manufacture of phosphorus, its employment in the improved process of candlemaking, in the isolation of stearin from crude tallow, its use by the dyer for preparing his colours, by the skindresser for opening the pores of the skin previous to the operation of tanning; by the metallurgist in the new process of refining silver; by the agriculturist in the preparation of most efficient manures,—I should have to unfold a picture for which it would be difficult to find the appropriate frame. Nor could I omit to show you Leblanc struggling with prejudice for the adoption of his great discovery: the transformation by the agency of sulphuric acid of sea salt into carbonate of soda; or to lead you into the busy factories of Lancashire, which now, after the lapse of less than half a century, provide not only this country, but half the world, with soda. Nor would the picture be complete without the glassworks and the soap manufactories in the distance, the operations of which have been forced into unprecedented activity by the production of soda, without the bleaching yards, which owe their very existence to Leblanc's great discovery!

It would be equally instructive to trace, in brief outlines, the history of *coal gas*, the manufacture of which has become, during the last thirty years, of truly national importance.

The evolution in different localities of inflammable gases from the ground has been noticed from time immemorial, and the connexion of these gases with deposits of coal had been recognized as early as the middle of the seventeenth century.\* Years, however, elapsed before correct views of the nature of these gases were established by experiment. In 1739, coal was for the first time subjected to distillation by Dr. Clayton, Dean of Kildare, who thus succeeded in imitating artificially the formation of native gas. From this moment the subject was never lost sight of, but it was not till the end of the last century that the intellectual impulse of that memorable period overcame the difficulties opposed to the practical application of this new source of light. These obstacles we know have been at last entirely removed; gas light is now universal. Our streets, our public buildings, our private dwellings, are brilliant with its radiance. In our daily enjoyments of its benefits, we have almost ceased to be conscious of the comfort and even personal security, which we owe to this, as yet, the best, cheapest, and safest of lights.

But, to the attainment of this end, how many were the scientific problems to be solved, how often had the gas-maker to seek the assistance of the scientific chemist, and to avail himself of the results of his researches, instituted originally perhaps for very different purposes! What a difference between the gas with which Mr. Murdoch lighted up the Soho foundry in Birmingham, and that now circulating in the arteries of our nightless towns!

The gas produced by the distillation of coal is not an uniform substance. Together with the principal illuminating constituents, light carbonetted hydrogen and olefiant gas, many other gases are evolved during the distillation, some of which, *e. g.* hydrogen, tend rather to diminish the illuminating qualities of the gas, whilst others, as ammonia and sulphuretted hydrogen are injurious to

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\* Mr. Shirley's experiments on the burning well of Wigan, in the Transactions of the Royal Society for 1659.



health. This formed a serious obstacle to the adoption of coal-gas as a domestic light. By the aid of chemistry, the composition of coal-gas was ascertained, and the nature of its constituents, useful and deleterious, determined. Founded on the knowledge thus obtained, means were devised for the separation of the latter; the temperature was indicated, at which the purest gas comes over during the process of distillation, whilst for the improvement of gas less rich in illuminating constituents, the beautiful and economical process of naphthalization was suggested. And, finally, simple and elegant burners were contrived for the safe and economical combustion of the product.

The extent to which the use of gas has affected the arts and manufactures in this country, can only be conceived by those who are aware of its innumerable applications in the double capacity of giving heat and light. The benefits afforded by gas to our experimental chemists cannot be overrated, more especially in England, where the price of spirits of wine was at one time so exorbitant. But for the use of gas in the laboratory, the progress of chemistry in this country must have been greatly retarded.

In speaking of the general influence of the manufacture of coal gas, it is impossible to leave unnoticed the number of hands daily engaged in raising whole strata of coal, and in loading and navigating the fleets employed in conveying it, not only to the different ports of this kingdom but to foreign countries, which consume a much larger quantity of English coal for the production of gas than is generally known. The extension of the gas enterprise produced a sensible effect on the iron works by the vast number of retorts, the stupendous gas-holders, and the endless pipes, required for generating, storing, and conveying the gas. Several other branches of trade were also forced into increased activity; and even new trades sprang up in consequence of the extended use of gas. The substances produced in the purification of gas naturally attracted the attention of the gas manufacturer; and chemistry soon pointed out valuable purposes to which they might be applied. The oily matter, which is separated as a secondary product in the distillation of coal, has been the subject of various chemical researches, amongst which must be singled out the elaborate\* investigation of Charles Mansfield, a young chemist of extraordinary promise, whom a cruel fate tore away too early from science and his friends. His researches showed the more volatile portions of this oil to consist chiefly of benzol, an interesting compound discovered some years previously by Faraday. The history of benzol alone and its uses, would fill a little volume. Capable of undergoing in the hands of the chemist an endless number of proteus-like transformations, this substance has not only assisted the progress of science itself, but given rise to new and important branches of industry. Let me remind you that benzol is the most convenient solvent for caoutchouc, that, as an agent for removing oil and grease, it has become an ordinary household article, that in perfumery and in confectionery we use it as a substitute for the essential oil of bitter almonds; let me remind you, lastly, that, converted by a succession of chemical processes into aniline, it has

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\* Charles Blachford Mansfield died (Feb. 1855), a victim of his scientific zeal, in consequence of an accident which happened to him whilst he was engaged in experimenting with benzol. The memory of this young man, in whom intellectual powers of the highest order were wonderfully blended with the rarest gifts of the heart, will be cherished by all those who had the good fortune of meeting him during his short but useful career.—A. W. H.



given rise to the production of those beautiful mauves, purples, and crimsons in which the lovelier portion of mankind is now indulging to the exclusion of almost every other colour. Nor have the other products of the distillation of coal, which accompany the benzol, proved less useful; the liquid distilling at a very high temperature was found to be an efficient preservative of timber, and the pitchy residue formed the chief ingredient of an excellent substitute for the flag-stones of our pavement, while the ammoniacal liquors were found useful in improving the fertility of land. Thus, after the lapse of countless ages, was the nitrogen of petrified fern forests resuscitated in the ammoniacal liquors of the gas works, to vegetate once more, and increase the produce of our corn fields.

In giving you a brief outline of the influence which the study of chemistry, by the development of the manufacture of sulphuric acid and of coal gas, has exerted on the progress of civilization of the present time, I have selected as illustrations two branches of industry, which are essentially of modern growth. Let us now glance at the benefits conferred by the development of chemistry on some of the arts, which formed the legitimate pride of antiquity.

Take *architecture* as an example. In Rome this art had reached the highest degree of perfection. The temples, the theatres, the aqueducts of the Roman architects, half ruined as they have been handed down to us, are justly admired as glorious monuments of their taste, of the vastness of their conception,—of their constructive powers. It is generally believed that the Romans have been the inventors of the ordinary mortars, some of their earlier buildings being constructed without the intervention of mortar. They certainly discovered the hydraulic mortars, which they subsequently used in all their marine buildings. The material originally used by the Romans in the preparation of hydraulic mortars, was the volcanic rock which abounds in the neighbourhood of Vesuvius, more especially near the town of Puteoli, the Puzzuoli of modern times. Ground to a fine powder and mixed with slacked lime, the dust of Puteoli, *pulvis Puteolanus*, has the remarkable property of hardening under water. When the Romans penetrated into Germany, they found the same material in the valley of the Rhine and in the volcanic districts of the Eifel. For nearly 2,000 years the rocks of Puzzuoli and the trass-quarries of the Rhine were the only sources from which this valuable article could be derived. It was reserved to the science of our own age to unravel the mystery of hydraulic mortars. The attention of scientific inquirers was forcibly drawn towards this subject, when, at the close of the last century, Parker and Wyatt made the important discovery that the calcareous nodules, which are found in the clay of the London basin may be converted by simple burning into an excellent hydraulic mortar which had moreover the advantage of requiring no addition of lime. Patented in 1796, this discovery led to an important branch of industry—to the manufacture of “Roman cement.” The question of hydraulic mortars had entered upon a new phase by becoming the subject of scientific investigation. Geology and chemistry were appealed to, and it was not long before a satisfactory answer was obtained. Several observers have participated in this examination, but it was not until a prize, proposed by the Society of Harlem, elicited in 1828 the classical inquiry of Fuchs, and based the production of artificial hydraulic cements upon a scientific foundation. It would transgress the limits of this fugitive sketch were I to trace, step by step, the gradual development of the chemical theory of hydraulic cements; the question has been very ably discussed by



Prof. Pettenkofer,\* who in our own days has materially assisted in the final elucidation of this subject. Suffice it to say that the conditions involved in the solidification of water-mortars are now known, and that every country possesses the materials for the artificial production of what was once the monopoly of the bay of Naples and the valley of the Rhine.

I might go on for hours quoting illustration after illustration, but I must limit myself to pointing out a few of the advantages which the most important branch of human industry, *agriculture*, owes to our science. At an epoch when the resources of the agriculturist seemed almost exhausted, chemistry offered her hand, to lead him up a new ascent of improvements. An accurate study of the composition of plants, taught us the actual nature of their food,—that it was partly obtained from the atmosphere, and partly from the soil. It taught, likewise, that while the nutriment derived from the air (identical for all plants), is continually restored to it by the never-ceasing processes of respiration, combustion, and putrefaction; the mineral aliment (varying with each vegetal species), is drawn from a source which is liable to exhaustion. The knowledge of the importance, to the development of plants, of a due supply of their mineral constituents, implied the recognition of the necessity of faithfully restoring to the soil such inorganic matters as are removed from it in our crops. This principle sealed the pledge of alliance between agriculture and chemistry. To keep up the fertility of his fields, the cultivator of the soil had to make himself acquainted with its general composition, as well as with the nature both of the particular substances, which he is annually extracting from it, and of those with which he must supply the loss. For each of these purposes the aid of chemistry became indispensable to the farmer. Davy's excellent work on agricultural chemistry first called the attention of the more intelligent British farmers to the value of chemistry in the improvement of their art, but it is only within the last twenty years that the attention of agriculturists has been generally directed to the subject, more particularly by the works of Liebig and Boussingault. The nature of manures once clearly defined, almost every agricultural improvement at which practice had arrived by slow degrees, received a satisfactory explanation, whilst a variety of improved applications necessarily suggested themselves. The principles of fallowing and of the rotation of crops, and the theory of soil-burning, are no longer mysteries; the action of lime, of wood ashes, and of bones is now perfectly intelligible. In this country, too high a value cannot be set upon the discovery of new sources of material convertible by the farmer into human food. Chemistry has put us in possession of the excreted wealth, which centuries had accumulated in the islands of the Pacific; and if the means which it has suggested for preventing the enormous waste of valuable matter perpetually and irrevocably swept away by the Thames and others of our large rivers, have not as yet been perfectly successful, it has enabled us to substitute for natural manure, artificial products, for the components of which the refuse of every trade and manufacture is now carefully sifted. Perhaps there is no more striking illustration of the value of the aid which agriculture has derived from her new ally, than the success which of late has attended the search for mineral manures. This search, directed by the philosophical interpretation of a few isolated facts, has been rewarded by the discovery of considerable

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\* Popular Lecture.



quantities of phosphate of lime in various parts of England; thus realizing the prophetic anticipation of Liebig, that "in the remains of an extinct animal world, England is to find the means of increasing her wealth in agricultural produce, as she has already found the great support of her manufacturing industry in fossil fuel, the preserved matter of primeval forests, the remains of a vegetal world."

Nor is the increase of his vegetal produce the only object in the pursuit of which the farmer relies upon the counsels of the chemist; in the feeding and fattening of his animal stock, he stands in no less need of his instruction.

And here we may briefly allude to the benefits, which *physiology*, *pathology*, and *medicine* in general, have derived, and must still further derive, from the prosecution of chemical inquiry. The investigation of the food of plants was followed by a no less vigorous scrutiny of the food of animals. The materials consumed by animals were shown to fulfil two distinct purposes in their economy, enabling us at once to separate into two distinct classes the substances supplying,—each respectively,—the aliments of nutrition, and those of respiration. In vegetal fibrin and albumen, we became acquainted with a group of nitrogenous compounds, which we find again in the animal organism as the chief constituents of the blood. These materials, prepared by vegetal life, the herbivorous animal receives and assimilates into its blood, to supply the constituents of its different organs and structures.

Again, we have a series of substances, such as fat, sugar, gum, starch, &c., which, though not truly to be called nutriments, as having no part in the construction of the body, are no less essential to the maintenance of life. These substances serve the process of respiration; combining with the oxygen inspired by the animal, they continually compensate the loss of temperature, and thus become the source of animal heat. And here presents itself one of the most interesting subjects for contemplation,—the animal organism in its relations to the surrounding atmosphere. The full appreciation of the effect of air and temperature on the animal system, was a most important step towards a true understanding of the conditions of health. A vast number of diseases originate in disturbances of the relation between the living system and these influences, the intimate knowledge of which affords to the physician the simplest, safest, and most efficient means of preserving health and of curing disease.

Valuable as have been the fruits of chemical inquiry, still more may be expected from the further prosecution of this study. The notion that the action of most of our medicines is chemical, is daily growing into a general conviction. We admit that with every change wrought by pharmaceutical agents in the state of our organism, there occurs a corresponding change in its composition, resulting from their reaction on one or more of its constituents. But of these transformations, which doubtless could be expressed in numbers as definitely as can our laboratory-processes, how few are we in a condition to explain; in how few instances has the physician even a vague conception of the mode in which any medicine performs its office! Nobody doubts the power, which the principles of the Cinchona bark, or of tea and coffee, exert upon the living body, but we are perfectly in the dark as to the way in which they act upon the animal economy. But if we meet with a series of similar substances in several animal fluids: e.g., *urea* and *creatine*, almost constantly present in urine, *glycocoll* generally, and *cystine*, occasionally, excreted in the same liquid, and if we find that all these

substances exhibit in their chemical relations a close analogy with *quinine* and *theine*, we begin to feel a sort of anticipation of the manner in which these agents may act upon the system. Such examples illustrate at once the nature of the aid which therapeutics may confidently expect from the progress of organic chemistry. Medicine some years ago found itself in a predicament very similar to that of agriculture at the same period; its resources appeared to be in a state of exhaustion, the rich capital of facts accumulated in the department of organic morphology by the industry of the anatomist, and by the acumen of the physiologist, could not yield its full fruits until an equivalent of knowledge had been drawn from the study of biochemical phenomena. This state of things, however, is rapidly changing; associated with chemistry, medicine no longer draws the veil of vitality over processes, the mystery of which may be unlocked by the key of analysis; it no longer shrinks from climbing, step by step, the ladder of recognition, because its upper extremity, disappearing among the clouds, seems to rise for ever beyond the grasp of inquiry. The special zeal with which the field of organic chemistry has been cultivated during the last thirty years, the simple and accurate methods which we now possess for determining the composition of organic products, the amount of analysis actually performed, and, more than all, the still untiring energy of the numerous labourers in the same field of investigation, hold out the promise that the connexion between medicine and chemistry, becoming daily more intimate, will be productive of benefits, the importance of which we can scarcely venture to estimate in the present state of our knowledge.

I have thus endeavoured to indicate some of the most remarkable features of the new field, into which the present generation has been conducted by the study of natural science, and especially of chemistry. I have tried to sketch the prospects, which a continuation of these labours promises to open before us. It remains to me now to consider the cultivation of chemical science under its other equally important aspect, as the unfailing source of the purest and highest intellectual enjoyment, and as a means of mental training, more effectual perhaps than any other discipline.

If poetic antiquity endowed with a new soul him who learnt to speak the language of another people, how shall we find a fit term to express the sharpening of our perception, the enlargement of our views, the opening of a perfectly new sphere of vision, accruing from the acquisition of a language which unfolds to us the comprehension of nature? Phenomena so common that we are accustomed to pass them by almost with indifference, how are they changed,—I might say ennobled,—by the light that science has shed over them! True it is that the guiding hand which, according to immutable laws, rules over the economy of nature may be recognised without the aid of science. It is visible to everyone who, with an open eye, looks into the world; but no one familiar with the mutual relations by which nature's phenomena are linked together, could deny that with each step forward in the field of research, the conviction becomes more deeply rooted, and that each new observation discloses a new source of the most elevated contemplations.

When glancing, in a former portion of this lecture, at the benefits arising to agriculture and medicine from the progress of chemistry, I have already hinted at the inquiries which have for their object the examination of the chemical conditions of vegetal and animal life, and at the light which they have thrown upon the true nature of respiration and nutrition. I am inclined to look again at these



inquiries from a different point of view. They have taught us that animal respiration is a true process of combustion; in order to secure the necessary warmth, we have to burn at every moment a part of our body; this source of heat lasts so long as we supply to the seat of combustion continually renewed fuel; so long as the alternation of breathing maintains the supply of the necessary amount of oxygen, and accomplishes the removal of the products of combustion, *i.e.* of water and carbonic acid. With each respiration the animal robs the atmosphere of a certain quantity of oxygen, and introduces into it a proportionate bulk of carbonic acid. If we consider that the endless processes of combustion, carried out for domestic purposes and for the purposes of industry, produce the same effect; that, lastly, the transformations of organic matter, which we designate as putrefaction and decay, are, in many respects, nothing but processes of slow combustion: it is evident that the unlimited continuance of these conditions must gradually involve a change in the constitution of our atmosphere. Such a change has not yet been observed. It has been justly argued that the immense space of the atmosphere necessarily renders changes of this sort extremely slow, that our analytical methods are not sufficiently accurate, that our experiments do not extend over a sufficient length of time; nevertheless, who could fail to perceive that the compensation is furnished by the difference of conditions which govern the life of the plant in contradistinction to that of the animal? With its leaves, as with so many lungs, the plant withdraws the carbonic acid from the air. Under the influence of sunlight the carbonic acid splits into its constituents—the carbon is employed in building up the plant, whilst the oxygen is returned into the atmosphere. The plant is referred, for its support, to the compound which the animal ejects from its organism as no longer serviceable for the purposes of its life; but it requires only a part of this compound; the rest is set free, again to take part in the development of a new animal generation.

How simple and how wonderful are the means which nature employs to fulfil her least, as well as her greatest designs!

A mine of interesting considerations is opened by the phenomena to which we have slightly adverted. The carbon of the plant is derived from the air, in which it exists in the form of carbonic acid. The carbonic acid is, as we have seen, partly furnished by the respiration of the animal; but in combustion as in decay a supply of carbonic acid no less inexhaustible is secured to the atmosphere. But with how new a signification do these processes become endowed when we view them in relation to vegetal life! Combustion, which suggests to the ordinary observer the idea of destruction—decay, which we are in the habit of considering as the symbol of death, in the eye of the chemist are but changes of form bearing the germ of a new unfolding of life. Of all the changes which surround us in nature how different are the views we take, when once the study of chemical phenomena has convinced us of the indestructibility of matter, when once we have accustomed ourselves to consider, as fixed and unalterable, the sum of matter which, under the influence of the forces of nature in the processes of vegetal and animal life, is capable of assuming so endless a variety of form!

Contemplations of even a higher order have been attached to this recognition. No one is likely to deny the danger of attempting to refer the conditions of spiritual life to the laws of the material world, still, this speculation, which appears so consonant to ordinary

conception, has been at all times indulged in. If in the gradual development of the cell, of the organ, of the animal,—each phase of which, although fulfilling a definite purpose of the present, nevertheless points to a future end as yet unfulfilled,—physiologists have seen but a special case of a much more general law, which governs likewise the unfolding and ultimate destiny of the human mind;—can we wonder that in the indestructibility of matter (the medium in which all these transformations are accomplished without a particle of it being lost),—chemical philosophers should with delight have imagined they had found a measure applicable to spiritual life, and that indestructibility of matter thus became to them a symbol of the immortality of the soul?

Thus we see emanating from the results of chemical inquiry a rich vein of considerations such as must be acceptable to every thinking mind; but these considerations are by no means limited to objects of general interest. No department of knowledge,—no branch of study,—can be imagined, but what might draw from the stores of chemical experience important solutions and significant suggestions. We find abundant proofs of this assertion in the chemico-agricultural, and chemico-physiological inquiries of Liebig, the general results of which are embodied in his admirable "Familiar Letters on Chemistry." The merchant, the political economist, the statesman, the ethnographer, the historian, each of them finds in this book numerous questions, in which he takes a lively interest, elucidated from the chemical point of view. Let us select a few examples from the superabundant material teeming on every page of Liebig's letters.

The *ethnographer* makes us intimately acquainted with the manners and customs of different nations, but how seldom does he go a step farther and attempt to explain such manners and customs (which are certainly not accidental) by referring them to the physical conditions of life of the respective nations, to the geographical situation, or the climate of the countries which they inhabit! We obtain the most circumstantial accounts of the dietetics of different races, we learn with a sort of discomfort the small portions of, as we should think, unsubstantial nourishment which satisfy the inhabitant of a tropical country, while we lay aside with disgust the bill of fare of the Esquimaux, informing us of the quantity of blubber which constitutes the chief ingredient of his meal. How clearly has Liebig proved the natural necessity for this difference in the choice and quantity of food, by showing that it depends on the quantity of carbon, the combustion of which, under given circumstances, is required for the preservation of sufficient warmth! We have as little reason to admire the South for its moderation as to reproach the North for its extraordinary appetite. Every one who has lived some time in a tropical climate recollects how his appetite diminished; whilst our Arctic travellers, as we see by their journals, become quickly reconciled to polar diet. It is well known, moreover, that the beasts of prey of the Arctic regions considerably exceed in voracity the animals of the torrid zone.

If the *historian* inquires into the causes of the decline and gradual disappearance of the North American Indians, he is led to the perfectly correct conclusion, that a combination of circumstances must be involved in producing so striking a result. In any case he will learn with great interest the chemical conditions which are contributing to this catastrophe. Viewed in the light of chemico-physiological experience, the extinction of the red population must be ascribed to the animal food on which the Indian, as hunter,



has especially to rely. The same experience has, in fact, taught us that a given surface of land, when serving the purposes of agriculture, is capable of supporting a number of persons from 80 to 90 times greater than when covered by forests inhabited by a nation of hunters. "Thus we see a scanty tribe of Indians dispersed over immense tracts of hunting ground, which must be considerably extended with the slightest increase of their number; and thus we understand the endless warfare which is decimating those red sons of the wilderness. It is no contest of principles, as with a civilized people, which, sparing the conquered, grants to him an honourable peace, but a mutual war of extermination—the desperate struggle for the morsel of bloody flesh which, like the beast of his forests, the Huron tears with his teeth!" (Schödler.\*)

It would be easy to multiply examples of the same kind, but I would rather allude, in conclusion, to the importance of the study of chemistry, as a means of education apart from the advantages (accruing from the acquisition of such a vast variety of positive knowledge), which I have endeavoured to point out in the earlier parts of this lecture.

No one doubts the influence which mathematical pursuits have in developing the mental powers. No one can deny that the precision of thought, the correct inference from given premises, essential to progress in mathematics, gradually becomes a habit, which is soon transferred to intellectual labour of any other kind. The mathematician starts from certain fundamental truths, which, without external aid, he is capable of elaborating out of his own mind; and on this basis he piles up, step by step, the wonderful edifice of his science. It is this nature-like mode of construction, disdaining to raise another stone before the previous one is thoroughly secured, which constitutes the value of mathematics, as an element of mental training.

The pursuit of chemical studies involves no less the development of the mental powers; it leads no less to precision of thought; it improves no less the habit of drawing correct conclusions, which, once acquired, is as easily transferred to other fields of mental labour. Chemistry, as a science, differs essentially from mathematics in this one respect,—that the truths which are its foundation cannot be drawn from the human mind itself. These truths are external to our mind, and can only be obtained by careful observation of the outer world; but, once our mental property, these experience-gathered truths afford a foundation equally adapted for the nature-like unfolding of a system of conclusions, which are not less logically linked together than the conclusions of the mathematician. The chemist has, however, this advantage over the latter:—whereas the mathematician has to find the guidance of his steps within himself, the chemist possesses in nature a mirror which, duly questioned, at every moment readily informs him whether he is still advancing in the right direction.

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\* Discourse on the Study of Chemistry as a means of Education.

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# LECTURES

ADDRESSED TO TEACHERS

ON

PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES

AND THE

METHOD OF TEACHING A SCIENCE CLASS.

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## LECTURE VIII.

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ON GEOLOGY,

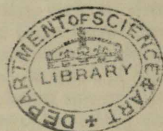
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# LECTURES

ADDRESSED TO TEACHERS

PREPARATION FOR TEACHING SCIENCE  
CERTIFICATE

## METHOD OF TEACHING A SCIENCE CLASS

It is a well-known fact that the method of teaching a science class is of great importance. The teacher should be able to present the subject in a clear and concise manner, and to make it interesting to the pupils. The following are some of the principles which should be followed in the method of teaching a science class.

1. The teacher should first of all make himself acquainted with the subject. He should know the facts and principles of the subject, and should be able to explain them in a simple and clear manner. He should also be able to make the subject interesting to the pupils.

2. The teacher should make the pupils understand the purpose of the lesson. He should tell them what they are to learn, and why it is important for them to learn it. He should also make them understand that they are to be active in the lesson, and not merely passive listeners.

3. The teacher should make the pupils understand the facts and principles of the subject. He should present the facts in a clear and concise manner, and should explain the principles in a simple and clear manner. He should also make the pupils understand the importance of the facts and principles.

4. The teacher should make the pupils understand the application of the facts and principles. He should show them how the facts and principles are applied in the real world, and should make them understand the importance of the application.

5. The teacher should make the pupils understand the method of the subject. He should show them how the facts and principles are discovered, and should make them understand the importance of the method.

6. The teacher should make the pupils understand the history of the subject. He should tell them how the subject has developed over time, and should make them understand the importance of the history.

7. The teacher should make the pupils understand the future of the subject. He should tell them how the subject is likely to develop in the future, and should make them understand the importance of the future.

8. The teacher should make the pupils understand the value of the subject. He should tell them why the subject is important, and should make them understand the importance of the value.

9. The teacher should make the pupils understand the method of the subject. He should show them how the facts and principles are discovered, and should make them understand the importance of the method.

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15. The teacher should make the pupils understand the future of the subject. He should tell them how the subject is likely to develop in the future, and should make them understand the importance of the future.

## LECTURE.

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PROBABLY no living man has a thorough knowledge of any particular science in all its branches. Each has grown so large, that if, instead of special research in one division of a subject, a man were to devote a lifetime to the mere acquisition of knowledge he would yet fail to master his science in all its bearings, especially now that so many of those lines of demarcation are broken down that of old were supposed to divide the sciences. Somewhere or other they merge into each other, and it is therefore often essential in working a subject to draw largely on others that at first sight might seem to have no immediate connexion with it. And did a man always foresee what he has to overcome in acquiring a sound and extensive knowledge of any science, before he can be in a position to extend its bounds, he might, perhaps, be so startled as to give it up without a trial; but, fortunately, most persons likely to excel commence their work, impelled thereto by an irresistible natural tendency, and are thus unconsciously carried on till they master their subject. Then, if possessed of sound judgment, united with the inventive faculty, these men may carry research into new regions, and advance our knowledge by their own personal exertions. Let all who feel it in them, start with this standard of what they have got to do, and though comparatively few reach a point so high, the mere acquisition of that knowledge which expands into the discovery of truths, new to them though sometimes old to others, will more than reward them for all their labour. Such is the not unenviable lot of the greater number of students, and of those earnest teachers who must in general be satisfied if they can appreciate the general bearings of a science, and know one or more of its branches well enough to be able to talk about it truthfully and clearly for the instruction of the ignorant.

The best method of doing this for geology is, I suppose, what many here wish to know, viz., how to learn the fundamental principles of the science and how to teach them, and this I will now briefly explain.

Geology as now understood has been defined to be the history of the earth, animate and inanimate, and in this sense it includes so much that no man can hope completely to master its details. Let any one turn over the pages of the Journal of the Geological Society, and there he will find a wonderful subdivision of labour on subjects chemical, mineralogical, physical, botanical, and zoological, in many branches; and in first-class manuals he will find the results of these researches summed up by persons who, with much knowledge of their own, know also how to avail



themselves of other people's work. But by far the greater part of such a journal is occupied with one set of questions, viz., those that concern the structure, mode of formation, and order of the rocky masses that form the crust of the earth, together with lists, figures, and descriptions of the fossils they contain; and till much more of the world had been accurately examined and geologically mapped this will necessarily continue to be the branch of the subject most widely cultivated, for it forms the foundation of the whole science. In ordinary terms, when the word geology is mentioned, this is what we think of.

A competent knowledge of geology is of great use in several professions, and some persons (but as yet far too few) commence the study of geology for professional purposes alone. Some are led into it inadvertently, their own peculiar science—perhaps of chemistry, botany, or zoology,—trenching on its borders; while the majority are at first led to investigate the grounds on which the conclusions arrived at by geologists are based, from mere curiosity. They wish to know “if there is anything in it;” if the world is really so very old, if it is a fact that numerous races of strange animals have become extinct, or if it is true that the living carnivora are the successors, and some of them the direct descendants of others that appear to have existed long before the creation of man; and some among these inquirers, finding that the fundamental principles of geology are well based and sure, begin to work practically for themselves, and led on by degrees, end by becoming active workers and perhaps discoverers in the science.

The chief use of scientific instruction in the lecture room is to teach a man how to teach himself. It is true that listening to clear familiar descriptions and sound opinions from a good teacher, especially in after-lecture conversation, clears away much of the rubbish that to beginners often obscures the subject. The listener may thus learn to feel the logic of the question, and see some way into its principles; but, after all is done, turn the lecture-taught geological student loose into the field among the rocks, and in practical matters he is little less ignorant than before. In spite of all the specimens on the lecture-room table, he is probably unable to give the lithological or geological name of a single rock he sees, he cannot “take a dip” or “a strike,” and the physical structure of the plains and hills—the reasons why they are so—are sealed to him, till by practice he is enabled, as it were in his mind's eye, to take a bit of the world miles in extent to pieces and put it together again.

For the systematic acquirement of geological knowledge, the first thing, then, that the learner has to do is to acquaint himself with the *lithological* character of rocks; that is to say, with those peculiarities of structure which indicate more or less the manner in which any particular rock was formed. This to some extent may be done in the cabinet by the aid of a good collection of specimens. Frequent examination, and, if possible, much handling of such specimens, will enable most people to distinguish between *igneous rocks*—the products of heat—and *aqueous rocks*, or those formed under the influence of water. Here and there difficulties occur, rendering it puzzling to determine to which class a specimen may belong; but these are exceptional, and in a large way the distinctions are always obvious. If, for instance, I compare the specimens on the table before me, it is evident that each has certain structural peculiarities native to itself. One specimen evidently consists of two distinct dark green and whitish substances mingled together. When attentively considered, these are seen to have a crystalline aspect, and if I appeal to a mineralogist, or work up my own knowledge of mine-

ralogy, I soon discover that the dark substance is hornblende and the light one felspar. Furthermore, if I compare the whole with certain of the rocks of a modern volcano, the formation of which we may perhaps have experience of, or the position of which establishes their origin, I find that with some of these it presents analogies so strong that I readily come to the conclusion that they were both the result of fusion, the crystals having developed themselves during the process of cooling and consolidation. A great number of the crystalline rocks, experience soon teaches us, necessarily come more or less under this category, and those that do not (such as the crystalline limestones) a more advanced stage of geological knowledge easily separates from truly igneous rocks. Again, if I take these three specimens, I observe that their base is *amorphous*, that is to say, it consists of a consolidated pasty-looking uncrystallised mass. What do we know of their manner of formation? This is a fragment of the slag of a Staffordshire iron furnace—an artificial lava—the result chiefly of the union of the residual silica, alumina, and iron of the ironstones with the lime cast into the furnace as a flux. It ran out of the tap-hole in a molten state, and the formation and expansion of certain gases formed roundish cavities in the mass, just as the fermentation of yeast blows out a loaf of bread. Here is another specimen from the lava stream of an active volcano, showing similar cavities, and at first sight scarcely distinguishable from the slag; and here is a third from the flanks of Cader Idris, where no volcano has blazed for indefinite ages, but of which a higher point of knowledge afterwards tells the learner, that volcanic phenomena were rife there in one of the earliest known stages of the world's history. In two of these cases actual experience tells us, and in the third the eye entitles us to assume, that the rocks from which the specimens were broken were originally formed approximately in the same way, viz., by the influence of heat, and that, while still soft and pasty, cavities were formed in them by the expansion of gases, which cavities in the old Welsh rock were afterwards filled up by the infiltration of lime in solution and its precipitation as carbonate of lime. If I examine a fourth specimen it is evident that, except that it is a stone, it bears no resemblance to the others. It is neither amorphous nor crystalline. On the contrary, when examined with the magnifying glass, it is found to consist chiefly of a number of half rounded grains of sand cohering together. Further, it is streaked in different colours of black and gray, the black being carbon or coaly matter, and the gray grains of quartz; and this other piece of rock is evidently composed of rounded pebbles, such as one sees loose on the sea shore, but in this case firmly agglutinated together. We call the first a sandstone and the second a conglomerate, and the appearance of the latter informs any one who has considered the subject, that the pebbles are rounded like those in many a running brook, or on the sea-beach, where the breaking waves rattle the stones against each other, and by attrition wear away their angles. In the sandstone the grains of sand are also like those on the sea-shore; and moreover they are *stratified* or arranged in layers, like the successive deposits of silt, for instance, at the mouths of some rivers, or anywhere else where sediments fall from a state of mechanical suspension in water. The third specimen we know to be a marine-formed limestone, for it consists in part of sea-shells, it is easily scratched with a knife, it effervesces with an acid, and if burnt it becomes white and then crumbles into powder on the application of water. These three specimens are thus known to have been taken from *aqueous* or *stratified* rocks, easily distinguish-



able from the *igneous* specimens first described; and so, even in the cabinet it is possible to acquire an empirical knowledge of rocks, which has an immediate though limited value when any one takes his first lessons in the field; besides which, it is at all times of use to students, and often to advanced geologists, to refresh their memories and increase their knowledge by the examination of mineralogical and geological specimens in private cabinets and in public museums.

But when practicable it is more instructive to acquire a first acquaintance with rocks by the personal collection of specimens in the field, for the collector may at the same time acquire much knowledge of the manner in which rocks themselves occur in nature in large masses. Many country people, especially those engaged in mines and quarries, have thus an extensive, though generally crude and empirical, knowledge of the *behaviour* of the rocks of their own district, and it is indeed quite remarkable how some of them, without being aware of its larger meaning, have a tolerably accurate perception of the physical relations of the strata of their own parish or county. This arises merely from those habits of observation sometimes induced by their occupations, and with a larger groundwork of knowledge the geologist must set to work somewhat in the same way. I first acquired my own knowledge of the geological structure of a country by an accident, and I cite this example, not as anything unusual, but as one with which I am necessarily most familiar, and which may be of use in showing how a certain amount of knowledge may be acquired. My curiosity having been excited by the desire of knowing what there was in this science that so completely remodelled people's notions with respect to the antiquity of the world, a little reading and much thought soon settled the question, as far as written testimony could go. I wished, however, to see for myself the actual evidence on which geologists founded their conclusions, and it happened that in preparation for a meeting of the British Association at Glasgow, a committee was formed to construct a geological map and model of the island of Arran, of which I was appointed a member. Circumstances threw the whole of the work into my hands. For the illustration of the subject I first undertook to collect specimens of all the rocks of the island, undeterred by the circumstance that when I took that responsibility I scarcely knew one rock from another. Still I knew that I could wield a hammer, walk, and carry well, and with much labour, exploring every hill and valley, I collected a great number of specimens, studied and arranged them by the help of the descriptions that existed, and in doing so, while still walking and working, the physical relations of the rocky masses to each other gradually dawned on my mind. I thus learned their order of superposition, partly realised the meaning of the granite and the metamorphic gneiss and mica schist, saw the nature of the common igneous rocks and the alterations produced by them, and by and by, growing bolder by experience, I was able to take advantage of the accident that the other members of committee let the subject alone, and I constructed a geological model and a map of the island on a scale much larger and more detailed than the only map that had preceded it, accompanying these with a book of geological description. There was nothing in this but what any one of ordinary sagacity might have done, whose bent lay in the direction of geology, and I merely mention it to show that a considerable amount of geological knowledge may be acquired by the method I now recommend. In fact as soon as a man understands the doctrine and nature of stratigraphical succession and superposition, not from descriptions and sections

engraved in manuals, but on the ground itself, he has made a great advance. Without it he may help in the solution of accidental questions in geology that may be raised in physics, chemistry, or natural history; but till he practically realizes the theory of superposition in the field, he can have but an imperfect idea, even of the meaning of a drawn section in a book, and he cannot understand the simplest geological map.

I have sometimes been accompanied in geological field-work by men of high reputation in other sciences, who seem incapable of realizing in their minds what may be called the solid geometry of the stratified rocks of a country (that is to say, the relative positions of the strata to each other) except in cases where they could actually see the order of superposition of scraps of the country in natural sections or quarries; but, as a general rule, most men of moderate capabilities, can by degrees make out and understand the structure of any country in which the strata have not been thrown into great confusion; and, with constant habit, so acute does the eye and mind become in geological observation, that the practised observer will make out at a glance facts explaining the geology of miles of country, where an ordinary eye would see nothing but wet and dry slopes on a hill-side, or a chaotic jumble of incomprehensible rocks.

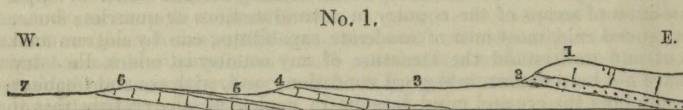
To learn a first lesson in this art, the best way is to procure a good geological map, and walk about the country with the map in your hands, comparing as you go the colours on it with the rocks that crop out to the surface in quarries, sea-side and hill-cliffs, brooks and river courses, road-side and railway cuttings, clay and marl pits, foundations of houses, well-sinkings, pit shafts, and even a new made grave in a churchyard, or a fresh molehill sometimes prove useful.

Several of the small geological maps of England and Wales and of Ireland are of some use for this exercise, especially those accompanied by good coloured sections, but for the purpose in view, I would specially recommend the maps constructed and published by the Geological Survey of Great Britain and Ireland. I recommend them, first, because the work was originally surveyed, and is published on an unusually large scale (the one-inch sheets of the Ordnance survey), and this sale, and the pains taken with them, ensured the mapping of the formations in a style of detail next to impossible for any but a government survey. Furthermore most of the sheets are accompanied by illustrative sections running right across the maps, and themselves explaining the order of the strata, the faults, and the nature of the igneous rocks of the district; and lastly, because their price is so moderate, that most persons could afford to buy the sheet or quarter sheet of the country that lies in his own neighbourhood. With such a map in his hand, a hammer, and if possible, a common compass and clinometer, any man may make a most important step in geological knowledge in a comparatively short period, by following the rocks on the ground, and constantly comparing them with the lines on the map. He will thus by degrees realize the reasons that induced the geologist to distinguish certain strata by different colours, and much may be learnt in this way, even if all the time he have to spare for the subject were included in accidental walks in the pursuit of business or recreation.

I have here on the wall five of these maps pasted together, comprising a portion of the old red sandstone of parts of Herefordshire, Monmouthshire, and Gloucestershire, the coal basin of Dean Forest, the Bristol coal field, the New red sandstone and marl on both sides of the Severn,




together with parts of Somersetshire and Dorset, and the Lias and Oolitic rocks on the east between Dursley, Bath and Bruton, and on to the coast west of Portland Bill. I will endeavour to explain how I would set to work if I were a stranger in that country and wished to understand its structure by help of the geological map. The most obvious manner of finding out the physical order, (if there be any), of the rocks coloured brown, yellow and green on the map, is the coast of Dorsetshire, where on the high sea-cliffs masses of different coloured sands, clays, and limestones range along the shore, and on the hills inland, somewhat in the manner shown in the following diagram:—



The horizontal line at the base represents the level of the seashore, and the undulating line, the surface of the country above the cliffs. Observe how each formation in succession, from No. 1 to No. 6, “crops out” or rises in the cliff to the surface towards the west, and dips down under ground eastward. Inland, you cannot, of course, see this prolongation of the beds under ground to the level of the sea, but narrow strips of strata of different kinds range through the fields, and you would be obliged to infer the underground prolongation of the beds to the east, or to sink a shaft and find it out, in which case you would find the inference to be correct; but here on the coast you are sure of it, for the sea waves have cut back and laid bare a *section of the country*, which enables us to inspect its inner structure. On the east, there is a rock that everybody knows by sight. It is Chalk, and if you get upon the top of the escarpment at 1, you can walk along its edge with a few interruptions all the way to Flamborough Head in Yorkshire, and far eastward to the coasts of Sussex, Kent, and Norfolk. But Nos. 2 and 3 are *seen* going under the chalk on the coast, and though an unpractised person would find it difficult to trace them all the way between, they are equally plain coming out from beneath the Chalk of Flamborough Head, and on the sea coast of Kent and Sussex, near Folkstone and Eastbourne. The inference is plain that the Chalk lies like a great cake in places from 600 to 1,200 feet thick, on the top of the underlying formations shown in the section, so that if you were to bore through it either in Yorkshire or Dorsetshire, and in most places between, you would come to the particular strata that in Dorsetshire we see cropping from underneath it on the coast. The same kind of reasoning applies to the other formations west of No. 3, and a skilful geological mapper can sometimes with difficulty, and sometimes easily follow them inland far to the north, where in many broad and narrow winding lines they crop to the surface in the plains and the sides of the hills. But to the unaccustomed eye the manner of doing this is not so clear, and I shall now endeavour to make it plain how I would set to work to find out the geological structure of a bit of ground in the heart of England, where natural sections are fewer and more obscure than those on the coast.

We will start with the neighbourhood of Bath, north of which there is a well known hill called Lansdown, flat-topped and on all sides surrounded by valleys. The question is, of what materials is this hill



composed, and how are they arranged? All round it in the valleys at its base, I find clay, brown at the surface, but blue where well dug into in pits or wells. I compare it with the map, and find it there called Lower Lias clay. If I ascend a little way up the hill on any of its sides, it appears that this clay is succeeded on the surface by a brown iron-stained soft and somewhat sandy rock No. 2, often full of fossil shells, and including at the top a mass of brown limestone. This on comparing it with the map is called Marlstone. Higher still the hill is formed of soft, pure, fine-grained sand, No. 3, of the colour of light brown sugar, by reference to the map called Upper Lias sand, and on the top of this in places I see a pale cream-coloured fossiliferous limestone, No. 4, often Oolitic, that is to say, composed of small rounded grains like the roe of a fish. These last formations make a dry soil, and higher on the hill the darker coloured grass and frequent patches of rushes indicate moister ground, caused by a substratum of tenacious blue clay, No. 5, containing thin streaks of shelly limestone, full of shells of the genera *Rhynchonella* and *Terebratula*, and small oysters. This clay, the map informs me, is called Fuller's Earth. Above this, within 10 or 20 feet of the top of the hill, springs break out here and there, at the base of a second bed of yellow fossiliferous limestone, No. 6, which I find is called the Great or Bath Oolite. Now, I am on the top of the hill. I walk along its flat top for a mile or two, and occasional quarries always show the same kind of limestone, while the ploughed fields are thickly strewn with fragments of the same. I go on round the summit of the hill on the edge of this dry escarpment of limestone, and always a few feet below on the slope I observe the wet, springy ground mentioned before, and infer (as shown on the map and in this section) that this limestone forms a cake covering the top of the hill. I descend and re-ascend the hill at several places, and always find the same succession of limestones, clays, and sand on every side, and I suspect that, like the upper limestone, these also lie in thick beds, which underneath the uppermost cake pass through the hill from side to side in the manner shown in the section. Should this inference want further confirmation, I find it in the cir-

cumstance that on the top of the hill near its centre, and well away from its edges, a deep well was sunk, in which several of the very same formations were passed through that I observed on its sides. Here then for Lansdown there is a clear order of superposition in the strata, that is to say, thick beds of rock of very different kinds are placed one upon another in regular succession, and if I take a clean map, and walking over the ground, trace upon the paper the upper and lower edges of each of these formations, and afterwards colour each one with a different tint, I construct a perfect geological map of Lansdown. This small matter accomplished, I wish to discover if the same rules apply to the neighbouring country, and perhaps to other more distant parts of England. I observe a little eastward of Lansdown a long escarpment looking westward over the valley of the Severn, intersected by valleys that wind inward from the plain. On the whole it stretches northerly by Dursley and Cheltenham, and if I choose to follow it further, with some interruptions, it will lead me right away into Yorkshire, where it turns eastward, and strikes into the sea. The plain of the

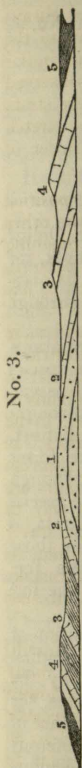


Severn is formed of New Red Marl and Lower Lias Clay, and always on the flanks of the escarpment that overlooks this plain, and far up the valleys that penetrate eastward into the country, I find strata similar to and in the same order of succession as those previously observed on Lansdown. I am therefore justified in the inference that these strata are also placed one upon another, and that the lower formations stretch eastward underground to an unknown distance in the same order of succession.

This then, as far as these rocks go, proves *the doctrine of superposition of strata*, and if we apply it to the rocks represented by any of the other colours on the map it is found to hold equally good. The meaning of it is that *the rocks are of different ages*. The matter, for instance, composing the lowest formation drawn in the foregoing sections has been formed of water-worn sediment mingled with marine shells, which often even now lie in the very positions in which they died, and these materials were therefore deposited in an old sea-bottom. Afterwards other strata of different texture were spread above it, and so on successively through all the varieties marked in the drawing, each being of later date than that which lies below, till on the top of all we come to the Chalk,—the youngest formation at present under consideration, as shown in diagram No. 1. Thus *each formation represents a separate stage in the marine history of the world*. In section No. 1, eight stages are represented, in section No. 2, only five; and I believe the best way to learn this by oneself, is to examine any tract of country in the way I have described, while the best way to teach it to others is to take them on the ground, and point out the phenomena; or if that is impracticable, to describe it by the help of maps, diagrams, and models in the manner I have done.

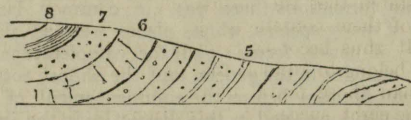
I have stated that the formations marked on the sections are fossiliferous all of them containing the remains of marine shellfish of many species. It thus becomes evident that the shells found in the lowest formation belong to animals that lived in an earlier stage of the world's history, than those found in the strata immediately above, and so on through the eight successive formations of the section till we come to the Chalk; and if it should be found *that in some degree or altogether, the shells of each formation are of species distinct from those of any other formation*, then by the fossils alone we shall be able to tell to what stage of the world's history these forms of life belong, and a clue is thus obtained to the history of the succession of marine life on the globe. This, which is called "*the succession of life in time*," was the great discovery of William Smith, "the father of English geology," first observed by him while conducting engineering operations, among the very Oolitic rocks I have described, in the neighbourhood of Bath. But William Smith was not considered a "great geologist," in those days. How should a self-taught man, who had not been instructed in the recognized formulæ of science, take precedence of all the regular orthodox workers by force of native genius alone? The prophet had therefore for long no honour in his own country; but at length the scales fell from the eyes of his geological contemporaries, and "*the succession of life in time*" became a recognized fact, not alone for the Oolites, but for every fossiliferous formation, first in Britain, and afterwards for the whole world.

To apply this to the maps and sections on the wall.



At the north end of this long map are certain patches of blue and purple. One of these, of a pear-shape, is known as the Woolhope district, and when its structure is analysed as shown in diagram No. 3, it is found to consist at the base of beds of sandstone No. 1, above which, arranged concentrically, there are three thick masses of limestone, Nos. 2, 3, and 4, interstratified with shales in the manner shown in the section. These are called Silurian strata, and above the highest bed of shale lie strata of deep red marl No. 5, belonging to a series of rocks called the Old red sandstone and marl. The Silurian rocks are fossiliferous, and contain many species of Trilobites, Orthoceras, Orthis, Leptæna, Strophomena, &c., and each subdivision of the Silurian rocks is more or less distinguishable from the others by its included organic remains. The Old red sandstone of this country holds no fossils, except a few fragments of fishes and crustacea, while in parts of Scotland it is comparatively full of fish remains. No fishes occur in the Silurian rocks, except perhaps just at their junction with the Old red sandstone, and no Trilobites or shells are found in the Old red sandstone of Herefordshire, and therefore, quite independently of colour, the organic remains alone easily enable us to distinguish the two sets of strata. If from the point where the lowest bed of Old red marl rests on the highest Silurian stratum we walk south towards Dean Forest, we shall constantly get higher in the Old red sandstone series No. 5,

No. 4.

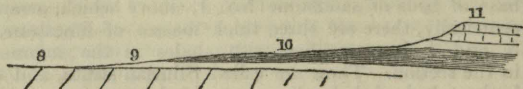


and at length, on the edge of the Forest, as shown in diagram No. 4, a great mass of limestone, No. 6, appears, on the top of which there are beds of sandstone and shale containing coal, Nos. 7 and 8. The limestone is clearly newer than the Old red sandstone, because it overlies it and for the same reason the coal-bearing strata are newer than the limestone. The fossils of the Carboniferous limestone, as it is called, when critically examined, are found to be of species quite distinct from those that occur in the Silurian rocks, and even many of the genera are new. So marked, indeed, is the difference, that any half-instructed person looking over a collection from both, cannot fail to be struck with the quantities of Trilobites from the Silurian rocks, and their great scarcity in the Carboniferous limestone, the heaps of Productas and Spirifers from the latter, and their absence or rarity in the former, and so on through many other marine forms, while in the Coal-measures there are found organic remains that lived on land, many tall trees, ferns, and other plants of species found in no other rocks whatever. Here in Dean Forest the Coal-measures form the highest rocks of the *Palæozoic* or *Primary* rocks of the district; but if we go south to the Bristol coal-field, we find unfossiliferous New red marl, No. 9, which forms a low



part of the *Secondary* rocks, overlying the coal-bearing strata No. 8, *unconformably* thus.

## No. 5.



Above the marl we find the Lias No. 10, above the Lias the Oolitic strata No. 11, on which in Somerset and Dorsetshire lies the Chalk, the highest member of the Secondary formations, which in its turn is overlaid by *Tertiary* clays and sands, the equivalent of those through which deep wells are bored to the Chalk in and round London.

As in the Palæozoic rocks, so each of these Secondary formations holds its own peculiar suite of fossils. Thus almost all the species of the Lias differ from those in the overlying Oolites; and if we ascend through the different formations of the Oolitic strata, we find throughout the series, that in contiguous formations some species are distinct, while many are often common to both; but if we compare the forms from the lowest and the uppermost of all the Oolitic formations, though the *genera* of shells in them are for the most part the same, the *species* are nearly all distinct. Passing upwards into the Cretaceous strata, it appears that every species found therein *differs entirely* from those characteristic of the Oolites; and all the shells and reptiles of the Tertiary strata above the Chalk, are again unlike those of any of the formations below.

The meaning of all this is, that during the successive deposition of the Silurian formations there was, in common language, a gradual extinction of many species, whose places were as slowly filled by the appearance of newer forms; and the complete change of species, the remarkable changes in the genera, and the almost total disappearance of some Silurian families before the commencement of the Carboniferous epoch, is clearly connected in this district with the intervening accumulation of 8,000 feet of nearly unfossiliferous Old red sandstone; for, during the enormous lapse of time that it took to form a succession of unfossiliferous strata so vast, all the old forms of life passed away and were replaced by new. Again, the unconformity between the Secondary and Palæozoic rocks means more than this. Here the Palæozoic strata have been contorted, heaved on end, and denuded—before the deposition of the Secondary rocks, the lowest member of which is the New red sandstone, which in England contains no remains of marine shells; and so vast is the gap in time between the disturbed and the nearly horizontal strata of the above diagram, that Trilobites, the Orthocera, and almost all the genera of Brachiopoda—the leading types of Palæozoic life,—have vanished, and their places have been filled in the lower Secondary rocks by other Crustacea, new cuttle fish, and legions of Conchifera of more modern kind. Between the close of the Oolitic and the beginning of the Cretaceous marine epochs, there is another complete break in the succession of life, for, while a great number of the generic forms are the same, all the Oolitic species died out before the Cretaceous forms began to live. The Oolitic rocks of our own and some other areas, were, in fact, raised above the sea to form land, and there remained so long, that when again submerged, the old forms had passed away and

other shapes prevailed. A similar gap, accompanied by a similar entire remodelling of forms, occurs in the change from the uppermost British Cretaceous to the lowest Eocene (tertiary) marine strata. Each of these great Oolitic, Cretaceous, and Tertiary subdivisions, therefore, *contains a suite of fossils peculiar to itself*, by which it can be distinguished, and each minor subdivision of the Oolitic strata, for instance, contains certain species so characteristic, that the formation can at once be identified by its organic remains.

Here, then, we have two great laws established—first, the doctrine of the *superposition of strata*, accompanied by, secondly, *the succession of life in time*; and the man who has thoroughly realised these facts, and knows how to apply them to rocks in the field, has already made advances in geology so great, that in any country, and especially in a new one, his observations might increase the sum of geological knowledge. It was by the application of these two principles alone, that, without assistance William Smith constructed his great geological map of the stratified rocks of England; the first, and, therefore, even independently of its excellence, the most wonderful geological map ever produced; and on these principles, since his day, every true geological map has been made; for the philosophy he propounded applies to the visible crust of the whole world, except in limited districts like Iceland, where all the rocks are said to be (probably erroneously) of igneous origin. The geologist must not, however, suppose that he can do without a knowledge of igneous phenomena.

Among rocks of all ages, from bottom to top of the geological scale, igneous rocks occur in some part of the world, sometimes intruded among them in masses, and sometimes interbedded with the strata in the form of true volcanic products. Thus the lower Silurian rocks of Wales, Cumberland, and Ireland are largely intermingled with volcanic rocks, while in Canada and the United States, &c. they contain none. The Carboniferous rocks of Scotland are full of lava-beds and volcanic ashes, while, except sparingly in Derbyshire, none are found in the greater Carboniferous series of England and Wales. The New red sandstone is free of trap dykes in England, except in rare instances, but I have seen them plentifully in the equivalent rocks of the United States and the Thuringerwald; and in Ireland and the Western Isles there are volcanic rocks believed to be of Secondary and Tertiary dates, while none are found in the contemporaneous strata of England. The learner must familiarize himself with the appearance of and effects produced by all kinds of igneous rocks, so as to be able to recognize and, if need be, to map or describe them. For this purpose let him study in museums, and collect in the field specimens of the crystalline rocks, such as granite, syenite, greenstone, basalt, amygdaloid, recent lavas if possible, and old and recent volcanic ashes; and further, let him master the mode of their occurrence under different circumstances. He will thus, often by their effects, be sure of them wherever he meets them, even though assuming an unlooked-for aspect. Thus, if he find certain

No. 6.





strata *a*, *a*, traversed by a crystalline or amorphous mass *b*, and if, when it reaches the top, it seems to have flowed over on all sides towards *B*, *B*, he may be pretty sure that a melted mass *b* has been injected into a fissure of the rocks *a*, and probably that it has overflowed at the surface *a'*, *a'*; and this inference will become a certainty if he find that the common stratified rock *a* is comparatively soft as a whole, but bleached, baked, and perhaps, as it were, porcelained at the points of junction, where in contact with the dyke and also beneath the overflow. In like manner, if we find that a great mass of felstone or basalt, for example, is fairly interbedded with strata of slate or shale, and if the bed below the igneous rocks has been altered by heat, and that above it remain unaltered, then the inference is fair that a lava stream ran out on the sediment, heating and changing that over which it flowed, but which cooled before the deposition of the overlying unaltered layers of (now consolidated) mud. If, however, a long line, say of greenstone, lie for a space ever so truly between strata which are altered both above and below, then it may be safely inferred that the melted matter was *injected* between the beds after the deposition perhaps of the whole formation, thus altering the strata with which it is in contact. So, also, it is often the case with granitic, syenitic, and greenstone bosses, that the stratified rocks all round are altered or metamorphosed, and branching veins proceeding from the main mass of the crystalline rock penetrate the adjoining strata. The observer will then have no difficulty in concluding that part of a heated fluid mass was injected into cracks of the surrounding beds. I mention these as the most familiar examples of igneous phenomena which must first be mastered, and, if possible, the eye accustomed to them, before the student proceeds to abstruser problems of metamorphism, &c., any account of which would be out of place here.

The next point to which I would direct attention is the practice of geological mapping. For this purpose the student ought to be provided with a good topographical map, on which to lay down his observations, a hammer to assist him in determining the nature of the rocks and in the collection of fossils, a clinometer to take the dip or angle of the strata, a compass to take the direction of dips and strikes, and a protractor to enable him with the help of his compass, to fix a doubtful spot on the map. By carefully tracing out the formations of any bit of country on a map, the student may be sure that he will acquire more really available practical knowledge in a short time than if he spent a lifetime in reading books. This practice, in fact, is what I would recommend to every teacher of geology. Let him master the geology of his own neighbourhood thoroughly, by the aid of such maps of it as are published, and if they are old and bad, if he have time, let him endeavour to improve them. Having done so, let him take his scholars if he can, now and then into the field, and there, map in hand, make them understand the stratigraphical relations and igneous phenomena of the rocks among which they walk, and if the district be fossiliferous, let them collect fossils, note their forms, and if they can find the means, name them and arrange them in the order of succession of the strata. If country teachers were once far enough advanced for this (and many without much labour could easily qualify themselves for it), a crop of geologists would spring up all over the country, and among them some valuable men would be sure to appear; and I venture to state that from such habits of observation, a vigour and enlargement of understanding would ensue, unusual in learners, who know nothing of maps beyond the hackneyed school-room series, and who merely learn geology from books and in-door talk.

Box 7

At the same time I do not undervalue geological teaching in the school and the lecture room. It is an indispensable part of all good teaching, especially in the more advanced branches of the science, and is all the more valuable when the teacher has acquired a certain facility in describing the structure of a country by the help of good diagrams, and with the aid of chalk and a black-board. Every good teacher of general geology ought, in fact, to be able to draw on the board with ease diagrammatic sections, which are not vague, unsteady, and ridiculously exaggerated, but being well proportioned, and firm in execution, will convey a truthful impression to the looker on. This is absolutely necessary in all the broader kinds of geological teaching; but no amount of facility in description can compensate for the want of a sound knowledge of the structure of the country around the provincial teacher's home, and, in thoroughly imbuing the minds of his scholars with that knowledge on the ground itself, he will render them a service which will be of use to them all their lives, even though after occupations should lead them entirely to neglect the subject.

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LECTURES  
ADDRESSED TO TEACHERS  
ON  
PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES  
AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE IX.  
NAVIGATION AND NAUTICAL ASTRONOMY;

DELIVERED AT  
THE SOUTH KENSINGTON MUSEUM,  
28th January 1861,  
BY  
J. RIDDLE, F.R.A.S.  
HEAD MASTER, NAUTICAL SCHOOL, GREENWICH HOSPITAL.



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May 1861.  
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# LECTURES

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## LECTURE IX.

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## LECTURE.

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It is my business this evening to make a few remarks on the leading points of modern scientific navigation, on the requisites of a teacher, and the method of teaching this important art, to expand and interpret the short programme laid down in the circulars issued by the "Department of Science and Art" bearing on this subject.

First then to the teachers, need I say that teaching and learning are inseparably connected; to be good teachers you must be good scholars. The terms are, in a great measure, convertible. He who most rationally and systematically applies himself to obtain a right understanding and a large and intelligent grasp of his subject, is best qualified to act as a pioneer to others in the field which he has himself explored.

Let it be remembered too that while an ignorant man cannot be a teacher, a learned man may yet, by lacking many things which books cannot teach, be almost as inefficient. Like all other arts, the art of teaching must be acquired by practice and patient observation of the ever varying materials to which it is applied. Have patience, endeavour to gain the great essential for a good teacher, equanimity of temper; your dullest scholar is teaching you how to teach.

The preliminary knowledge requisite for the study of navigation is specified under the head of group I. in the forms relating to the examination for navigation certificates, and it is fitting, therefore, that a few words should be devoted to this part of the subject.

Of arithmetic little need be said, forming, as it does, a staple article of instruction in all schools. Skill, dexterity, neatness of arrangement in working arithmetical problems, something of the philosophy of arithmetic, and expertness in vulgar and decimal fractions, we shall suppose are conceded.

In teaching algebra, I collect a large number of equations, both numerical and literal, carefully arranging them in the order of difficulty, and thus proceeding carefully, step by step, with abundant illustrations, pupils never fail to acquire great facility in the solution of all such difficulties as are likely to be met with in the investigation of their navigation or astronomical problems. This is a very important branch of algebra, one of constant application; but much more than this should be demanded of the trained teacher; he should be expert in the solution of problems, and acquainted with all the ordinary artifices of algebra—the proofs of the binomial and exponential theorems, and their application to the theory of logarithms, with which he will have so much to do in his calculations.

With these requisites in view, my examination papers have always contained questions calculated to expose the possession of them by young teachers.

What of geometry? the very groundwork of all scientific teaching, that science of which Dr. Whewell says, "The recollection of the truths of elementary geometry has, in all ages, given a meaning



“and a reality to the best attempts to explain man’s power of arriving at truth.”

Surely nothing need be added to this testimony, nothing from my feeble utterance would add strength to your own convictions, that the study of geometry is an essential mental discipline, without which no training is worthy of the name of education. But with reference to those practical arts which are at present under consideration, it is not only important on these high educational grounds; its propositions are our tools, an indispensable part of our stock in trade.

In learning trigonometry with a view to applying it to navigation and nautical astronomy, the leading formulæ must be committed to memory as soundly as the alphabet or multiplication table. With this view I make young pupils of from 14 to 15 years of age repeat them in the same manner as the arithmetical tables are conned.

Please to remember that it is one thing to read mathematics as mental gymnastics for the purpose of developing hidden intellectual forces, with purely educational ends, and quite another thing to learn mathematics with a view to transmute them into the mechanism of a practical art. These formulæ then become our tools, and they must be kept sharp, bright, and always ready for use.

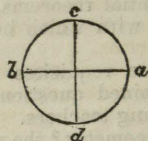
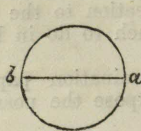
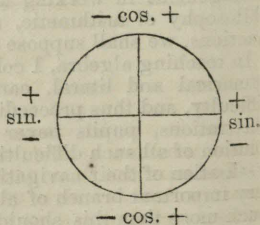
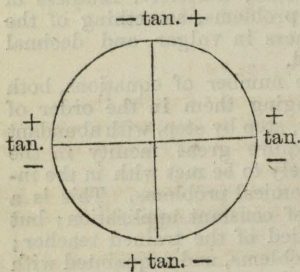
My prescription is, take Jean’s trigonometry and work out at length all the examples in both parts of his excellent and thoroughly practical little book.

The knowledge in this branch should be especially exact and critical. The use and force of the algebraic signs, as applied to the trigonometrical functions, must be thoroughly mastered, this will save you much vexation in the applications of spherical trigonometry, this alone will save you from such mistakes as I sometimes meet with, as—

$$\cos. 135^\circ = \sin. 45^\circ.$$

This makes no great demand upon the memory, for no angular measure that occurs in navigation or nautical astronomy ever exceeds the limits of the first and second quadrants.

Some such diagram as this will also aid memory :—



sin. and cosec.

cos. and sec.

tan. and cot.

The student should never lose sight of the numerical character of the quantities symbolized under the forms—

Sin.  $A$ , cos.  $A$ , tan.  $A$ , cot.  $A$ , sec.  $A$ , cosec.  $A$ .

That sin.  $A$  and cos.  $A$  are always fractions, either positive or negative, and that their effects as factors is to *lessen* value, and that a multiplication by *sec.* and *cosec.* *increases* the numerical value.

That multiplying by tan.  $A$  may either increase or diminish the value according as  $A$  is more or less than  $45^\circ$ . Such observations as these enforced by proper illustrations in elementary instruction will be found of great use in scanning trigonometrical formulæ, and will often help to detect errors or inadvertencies in them.

Beware of that bugbear of elementary trigonometry—

$$\cos. A - \cos. B = -2 \sin. \frac{1}{2} A + B. \sin. \frac{1}{2} A - B.$$

This formula properly handled is, of itself, an excellent lesson.

It is only a critical knowledge which can enable you to select amongst equations all *mathematically* true, those best applicable for the *practical* purpose in hand.

No one will attempt the accurate computation of a very small angle by means of the value of its cosine; nor of an angle nearly  $90^\circ$  by means of its sine.

As an example of the nature of the examination you may be called upon to make, the following one, taken from a popular little book on trigonometry, will perhaps prove instructive.

$$\cos. a = \cos. b. \cos. c + \sin. b. \sin. c. \cos. A.$$

$$= \cos. b. \cos. c + \sin. b. \sin. c. \left( 2 \cos.^2 \frac{A}{2} - 1 \right)$$

$$= \cos. \overline{b+c} + \sin. b. \sin. c. 2 \cos.^2 \frac{A}{2}$$

$$= \cos. \overline{b+c} \left\{ 1 + \frac{\sin. b. \sin. c. 2 \cos.^2 \frac{A}{2}}{\cos. (b+c)} \right\}$$

$$\text{Let } \frac{\sin. b. \sin. c. 2 \cos.^2 \frac{A}{2}}{\cos. \overline{b+c}} = \tan.^2 \theta$$

$$\cos. a = \cos. \overline{b+c}. \sec.^2 \theta$$

Now in a spherical triangle it will frequently happen that  $\overline{b+c}$  is greater than  $90^\circ$ , and in this case  $\tan.^2 \theta$  will be a negative quantity, or tan.  $\theta$  will be imaginary. This is then a very unpractical formula, tempting as it appears at first sight.

You must not be content with arriving at your final equations, you must weigh and measure them, patiently tracing out all their conditions and their consequences.

By thus persevering to the end you have your reward in many ways, and some of them, it may be, very unexpected. *Accuracy*, the great end aimed at, is secured. The memory, instead of being burdened is relieved by the analogies which the close study of the subject reveals.

Of this kind of relationship the principal formulæ of plane and spherical trigonometry afford prominent examples.

Here is another interesting one:—

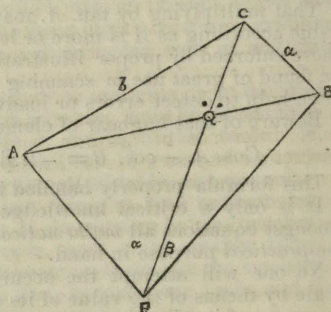
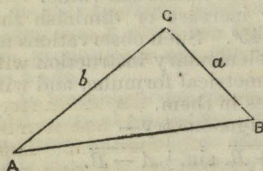
$$\text{In a plane triangle } \frac{a+b}{a-b} = \frac{\tan. \frac{1}{2} (A+B)}{\tan. \frac{1}{2} (A-B)}$$



In the problem for finding the position of a ship by means of the observations of three known objects on shore.

$$\frac{m+n}{m-n} = \frac{\tan. \frac{1}{2}(A+B)}{\tan. \frac{1}{2}(A-B)}$$

Where  $m = a \cdot \sin. \alpha$  and  $n = b \cdot \sin. \beta$ .



Now were the point of observation at  $Q$  instead of  $P$ , then  $\sin. \alpha$  would  $= \sin. \beta$ , and the two formulæ after reduction would be identical.

The last is, in fact, only a more general form of the first; there is not only an accidental resemblance, *it is a family likeness*.

The teacher will find sometimes, while carrying on, in parallel lines, his teaching in Euclid, algebra, and trigonometry, occasional difficulties arising from the interlacing of these subjects. He will feel himself called upon to appeal for aid to geometrical truths which his pupils have not yet attained. There is no necessity that this should bar his progress. The nature of geometrical demonstration once understood in the earliest propositions of Euclid, a point of mathematical faith is reached by the scholar on which the teacher may safely rest as a basis, whilst explaining the nature of those advanced propositions required for his present purpose.

Occasionally illustration, commonly called ocular demonstration, may be substituted for the more legitimate process of pure demonstration, and, indeed, with an effect often more convincing to young minds not disciplined to the force of logical demonstration.

For example, that the three sides of a spherical triangle are less than the circumference of a great circle.

That two of its sides are less than the third.

That the plane angles which form a solid angle are less than four right angles.

These may be illustrated by pasteboard models.

Do not, however, confound illustration with demonstration, as I sometimes observe a disposition to do, in the substitution of Napier's rules for the circular parts for a demonstration of the relations of the parts of a right-angled spherical triangle.

This is confounding cause and effect; Napier's rules are a result (curious enough in their way, but unimportant) of those very equations which are attempted to be established by their aid.

Navigation and nautical astronomy are the two great co-ordinate divisions of the "Art of Sailing on the Sea," as the old writers quaintly worded it.

By the first is generally understood the branch of the art which is accomplished by means of the log, compass, and chart; and relating to the art of directing the ship's course under the varying forces of winds and currents, and the estimation of her change of place.

Nautical astronomy needs little definition, it is that branch of practical astronomy by which the observer's situation on the globe is ascertained, by comparing the position of his zenith with relation to the heavens with the *known position of the zenith of a known place* at the same moment. The principal instruments are the sextant and chronometer and the Nautical Almanac.

In teaching navigation, we must commence with the imaginary lines of the terrestrial sphere, and definitions of latitude and longitude, difference of latitude, and difference of longitude. The mariner's compass must be learned, and exercises on allowing the variation must be given. By the way, we adopt a concise and safe artifice for the application of these corrections for variation, in the employment of the three initial letters—

### *E. T. W.*

as a substitute for a verbal rule. *T* standing for "true course," *E* for "easterly variation," *W* for "westerly variation." The position of *E* on the *left* of *T* denotes that easterly variation is to be allowed to the right of the true course to obtain the compass course, and *W* on the *right* of *T* that westerly variation is to be allowed to the left. I do not despise, in practical teachings, memorial aids such as these.

Moreover, the significance of *right* and *left* on the face of the compass card is explained thus, to the *right* is as the hand of the clock goes, and *left* the other way.

The relations between course, distance, and difference of latitude come next, and it must be shown by the sphere that—

$$\text{Difference of latitude} = \text{dist.} \times \cosine \text{ course.}$$

I have often received a very unsatisfactory reply to the question, "Is this generally true?" I find too often a desire to apply unnecessary limitation to this fundamental theorem.

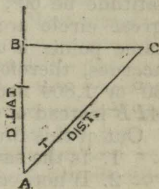
The right-angled triangle, commonly employed in the solution of problems in plane sailing, is merely a geometrical interpretation of this equation. Thus, if *AC* be a line as long as the rhumb line and *A* be equal to the course, *AB* must be equal to the difference of latitude, for it is equal to

$$\text{Distance} \times \cosine \text{ course,}$$

which is the necessary condition given by consideration of the sphere.

*BC* is a consequence of this geometrical interpretation, and has no direct counterpart in any line on the sphere. If the earth were really a plane and the straight line *AC* really the ship's track, it would measure how far the ship had departed from the meridian—from this it receives its name of *departure*. I say that it has no direct counterpart in any line on the sphere, still we can infer that it is nearly equal to the distance of the meridians between which the track lies, in the middle latitude, and thence by the geometry of the sphere that—

$$\text{Departure} = \text{D. longitude} \cdot \cos. \text{mid. lat.} - \dots\dots\dots A,$$





add to this the two equations derived from the right-angled triangle just referred to, viz.—

$$\begin{aligned}\text{Departure} &= D. \text{ lat. tan. course.} - \dots\dots\dots B \\ \text{Departure} &= D. \text{ lat. sin. course.} - \dots\dots\dots C,\end{aligned}$$

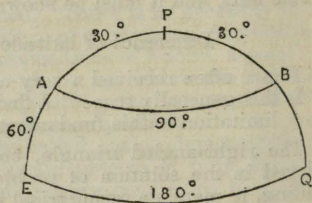
and by the combination of these the leading problems of navigation may be solved.

Mercator's chart can be only *popularly* explained to an ordinary class, the mathematical theory of the division of the meridional lines requiring at least a knowledge of the differential calculus; but this is not an excuse for *teachers* who come up to take certificates. Whatever is necessary for a right understanding of any branch of the art they undertake to teach, should be acquired by *them*. No part, however, of the *practical* teaching, so far as I have hinted at the major divisions of navigation, requires more than a knowledge of plane trigonometry.

Great circle sailing, however, which must now be included in teaching of navigation, demands a good acquaintance with spherical trigonometry, and if I may be permitted to say so, the second method of solution given in my navigation, if thoroughly mastered, will be found as convenient as any. I do not like mechanical methods of solving mathematical problems, nor do I think that the substitution of manual dexterity for calculation in their case, is accompanied by any equivalent gain in time, while there is always a sacrifice of accuracy.

The great circle charts, on the stereographic projection, recently published by Mr. Bergen, a master mariner, in which he avails himself of the well-known property of this projection, viz., that it reduces all great circles to straight lines, are simple and ingenious, and may be used to check calculations.

The following is a neat illustration of the gain of distance resulting from using the great circle, instead of the rhumb line connecting two places. *A* and *B* are two points on a parallel of latitude *AB*; and *AB* forms the ordinary rhumb line joining *A* and *B*, cutting their meridians at right angles; now if the latitude be  $60^\circ$ ,  $AB = 90^\circ$ , but the great circle arc *APB* joining the same points is only  $60^\circ$ . A saving accrues, therefore, of no less than  $30^\circ$  or 1,800 nautical miles, by proceeding from *A* to *B* on the arc *APB* instead of on the parallel *AB*.



Out of this illustration naturally grow such questions as these:—

1. Is the saving the same on all parallels?
2. If not, on which parallel would it be the greatest?
3. How would the answer be affected if the difference of longitude were limited?
4. How must two points be situated that there may be the greatest difference between the rhumb line distance and great circle distance?

This series of questions represents a progressive ascent from a very limited particular question to its most general form.

The general expression for the latitude of two places on the same parallel when the distance saved is a maximum, is—

$$\text{Cos.}^2 \text{ lat.} = \frac{1}{\sin^2 \frac{d. \text{ long.}}{2}} - \frac{1}{\left(\frac{d. \text{ long.}}{2}\right)^2}$$

and when the diff. long. =  $180^\circ = \pi$ , the formula assumes the elegant and simple character—

$$\text{Sin. lat.} = \frac{2}{\pi}$$

whence the latitude =  $39^\circ 33'$ .

The saving, in this instance, is 2,274 miles, and is the greatest possible, supposing the whole globe a navigable sphere of water.

I cannot leave the subject of navigation without a word on Halley's singular navigation enigma. The enunciation of his question is remarkably simple, but the direct solution has called up an amount of laborious calculation which I think it would be difficult in our own day to evoke in such a cause. The problem is this, "Given the latitude sailed from, the distance run, and the change of longitude, to find the course and latitude arrived at?" The tentative method of Dr. Mackay will solve it in a few minutes.

In teaching nautical astronomy, the first thing to be done is to give clear conceptions of the circles of the celestial sphere, and of the meaning of the terms employed, *i.e.*, the vocabulary of the science. The zenith and nadir,—horizons, sensible and rational,—vertical circles recognizable under their other convenient designations of azimuth circles and circles of altitude. Make your pupils point out the positions of these fixed circles in the heavens, the meridian of the observer, the prime vertical, the horizon. Let them draw diagrams illustrating the relative positions of these circles; and placing points to represent objects in various positions, make them show the altitude, zenith distance, and azimuth of them.

Next demonstrate the simple but important fact, that the elevation of the pole is equal to the latitude of the observer, then add to the diagram the poles, equator, and circles of declination, and let the scholar practise as before, in pointing out the declination, polar distance, and meridian distance or hour angle, of points, arbitrarily marked upon your diagram. Make him learn to discriminate between altitudes above and depressions below the horizon, and state whether the points marked would or would not be within the limits of vision, make him point in the sky the situation of your arbitrary points in the diagram, until he readily associates the bald geometrical lines with the actual sphere of the heavens. Next introduce the parallels of declination, and assuming any point to represent a star, trace the apparent diurnal path, marking the notable positions, as the places of superior and inferior transit over the meridian, the points of rising or setting, positions on the prime vertical, and on the six o'clock hour circle. Be careful to point out the position of the equator in the heavens, passing through the east and west points of the horizon, and crossing the meridian at an elevation equal to the co-latitude. Let these exercises always be accompanied also with a clear verbal definition of every circle, angle, and measurement referred to.

Show the conditions under which an object is seen both at its superior and inferior transit, illustrating them by special application to the sun.

Next let the ecliptic form the subject of a special lesson. Show how the motions of the earth impress apparent motions on the body of the sun; that the rotation of the earth causes no derangement of the relative positions of external objects (sun, moon, and stars) amongst themselves; that a motion of translation in the point of observation produces such derangement in various degrees, depending on the proximity of the objects observed. Show how the progress of the



earth round the sun causes the sun to appear to move from place to place amongst the stars, and how the inclination of the earth's axis causes this apparent path to intersect the celestial equator. Next will naturally come the variations of the sun's declination; when the "Nautical Almanac" should be referred to: and as a fitting practical conclusion to such a lesson, exercises should follow in calculating the sun's declination for a given Greenwich date; leaving for another lesson the division of the ecliptic into signs, the definition of *right ascension*, &c., when you may point out the want of coincidence between the signs of the ecliptic and the constellations of the zodiac bearing the same designation, the consequence of the precession of the equinoxes. Be careful to point out that the apparent annual motion of the sun is in the opposite direction to its apparent daily motion.

Of course the corrections of the apparent altitude of the heavenly bodies must furnish special and elaborate lessons. The first much of the same nature as those which I have glanced at, combining geometrical description by diagrams with careful verbal enunciation of definitions of dip, refraction, parallax, true altitude, apparent altitude, &c.; further lessons amplifying the subject by introducing the demonstrations of the mathematical relation between dip and height of eye; between parallax in altitude and altitude.

$$\text{Par. } \times \text{ in alt.} = \text{hor. parallax} \times \cos. \text{ app. alt.}$$

Also augmentation of moon's semi-diameter, &c.; ending such lessons with calculations of dips, parallax, &c., and corrections of apparent altitudes.

Another, and very troublesome branch of this teaching, is that which relates to the division of time. Begin by pointing out the sun's daily return to the meridian, and that his transit marks the commencement of the astronomical day. Show that the apparent motion in the ecliptic retards these returns, and makes the days longer. Next, that the inequality of this motion produces inequality in the intervals of return; and thus the inequalities of apparent solar time are accounted for. Mean solar time, and equation of time, follow. Follow this up with the diagrams illustrating the measurement of time by the angular distance of the true and mean sun from the meridian; and exercises on finding corresponding mean and apparent solar times by means of the equation of time given in the "Nautical Almanac," particularly impressing the difference between *12 o'clock and noon*, by repeatedly proposing such questions as these: "Is the sun east or west of the meridian at 12 o'clock on May 12?" "What o'clock should it be (at Greenwich) when the sun is in the meridian?" &c. &c.

Another lesson will follow on sidereal time and its relation to mean solar time.

Another on the difference of times at different places; always giving copious geometrical illustrations, constant references to the heavens, making your pupils draw imaginary diagrams in the sky, and at the same time giving careful verbal enunciations to the description of every technical term.

The difference of time corresponding to difference of longitude, and the calculation of differences of longitude from difference of time, will furnish subjects for many useful exercises; together with the important uses of the chronometer.

The reduction of the *intervals of time indicated by the chronometer* to correct intervals of true solar, mean solar, or sidereal time, tend to give more accurate notions of their relations.

The exercises I have indicated furnish an elementary or preparatory course, and afford ample opportunities for exercising the student

in extracting the various elements contained in the columns of the "Nautical Almanac."

I repeat that the problems relating to time are amongst the most trying to the student of nautical astronomy.

I find more mistakes in managing the reductions of dates, and conversions of intervals, than in any other calculations.

Although every one knows that

$$A + B - C + D$$

will give the same numerical result as

$$A - C + B + D,$$

many instances may arise in which the substitution of the one order of operations for the other may display a lamentable ignorance of principles.

I met, not long ago, with the following bad habit in a calculator, otherwise very respectable—

\*'s mer. dist. — mean  $\odot$ 's R. A. + \*'s R. A. = mean time,

to which he added the gratuitous piece of intelligence that

\*'s mer. dist. — mean  $\odot$ 's R. A. = \*'s mer. dist.

Again: To find the sidereal time at a given date, I am told to convert the elements of the given date into sidereal time by the table of time equivalents in the "Nautical Almanac!"

After these definitions and exercises are well accomplished the problems for finding latitude, longitude, variation of compass, and error of chronometer, come successively under consideration; every one of which, involving special mathematical considerations, requires careful teaching. As an example, it may be as well to illustrate the method pursued in teaching the problem of finding the latitude by means of the altitude of the pole star.\*

In the "Philosophical Magazine" for June, 1822, the late Francis Baily, Esq., drew the attention of English astronomers to a method of deducing the latitude from altitudes of the pole star at any time, which had been published by M. Littrow in 1827 the "Zeitschrift für Astronomie," vol. iii., p. 208, the formulæ being identical with those which occupy so prominent a place year after year in the "Nautical Almanac."

This paper is followed by "Further Remarks" in July, 1822, in which the history of the problem is given, with the conclusion that though it appears that a general discussion of such observations most probably originated in our own country, that the first *correct* solution of the problem is that of Mr. Littrow.

Subsequently to these papers the problem was dignified with a very prominent place in the title page and tables of "Schumacher's Ephemeris," and after the change in the form of the "Nautical Almanac" (1835) Schumacher's tables were adopted in its pages, and until 1845 the following statement relating to them was annually repeated in the preface.

The tables for finding the latitude of a place by observation of the pole star ( $\alpha$  Ursæ Minoris) at any hour of the day are similar to those published annually by Professor Schumacher in his "*Ephemerides of the Planetary Distances*," and are founded, &c. &c.

In 1845 and afterwards the sentence in italics is omitted; in all other respects the statement has remained unchanged to the present time.

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\* See Riddle's Navigation.



Whatever may have been the advantages afforded by these tables at the time that their celebrated author gave them so prominent a place, it has long been my opinion, that they do not worthily occupy the large space devoted to them annually in the "Nautical Almanac."

The first table contains the values of  $p \cos. h$ , calculated with mean values of the polar distance and right ascension of the star. This renders necessary Table III., which gives the corrections due to the fluctuations of the true values from the mean values, a minute or two being added to render the contents of the table positive, which still further obscures the principles of the problem.

The second table contains the value of

$$\frac{1}{2} (p. \sin. h)^2. \tan. \text{alt.} \sin. 1'',$$

generally a comparatively small quantity, not sharing in any degree in the complements of Table III.

From their complicated and unpractical character, I have long ceased to employ these tables; and I am sure that they are very rarely, if ever, used by anybody.

In order to obtain the results given in the example of their use, which is also annually furnished in the Explanation of the contents of the "Nautical Almanac," a troublesome interpolation is necessary with Table I., and, if possible, a more vexatious one with Table III., while the Almanac furnishes the means of finding the correct value of  $p. \cos. h$ . by the addition of two logarithms.

These two tables I. and III. deserve no place in the "Nautical Almanac;" they contribute only to obscure the problem, and afford very little, if any, facility to its solution.

The second table, which gives  $\frac{1}{2} [(p. \sin. h)^2. \tan. \text{alt.} \sin. 1'']$  might with advantage be extended, and given for shorter intervals of sidereal time, and might be rendered more compact by condensing the minutes and seconds into seconds only.

I should prefer the meridian distance ( $h$ ) for an argument, as showing more directly than the sidereal time does, the connection between the table and the formula upon which it depends.

The late Dr. Inman gave in his tables the total mean correction, tabulated with the latitude and sidereal time as arguments. This, as an approximation, may not be without its value to seamen, who prefer the "rough and ready" to more laborious accuracy; and it must not be omitted, in a sketch of the present position of this interesting problem, that the Board of Admiralty have recently ordered the recalculation of Dr. Inman's tables, the tables contained in the "Nautical Almanac" for the same purpose notwithstanding.

It is always well to exhibit the actual value of the corrections in the geometrical diagrams, as you will see that I have done in my solution of this problem. You must not be content with the mere attainment of the final equations; you must go back and show how they agree with the geometrical conditions, which are but too apt to be forgotten while following out the analytical reductions. By substituting different values, the various modifications of the problem must be traced from the established general equations.

Then comes the solution of numerical examples. In this I insist on neatness and careful tabulation; a special and distinct place for every subordinate fragment of calculation. Upon this orderly system depends very much of the accuracy, without which all your labour is in vain in these often complex calculations.

The calculations having been completed, make your scholar, by means of close questioning, describe every successive step in his work, that he may be impressed with its necessity, and see its proper place in the order of his tabulation. Let no portion of the subordinate calculation be performed on loose scraps of paper, and thrown aside; but, being essential to the accuracy of the results, let them have a place in the tabulation. This is easily accomplished, and affords the greatest facility for re-examination when necessary.

The method of finding the latitude by altitudes of the sun near noon is a ready, easy, and accurate one, very well deserving of more attention than it generally receives; and I would recommend a diligent attention to it on the part of those who are teaching navigation. It is a simple problem, and I will venture to show how we discuss it with boys at Greenwich.\*

*Red. to Meridian.†*

The ordinary formula for the computation of the reduction is—

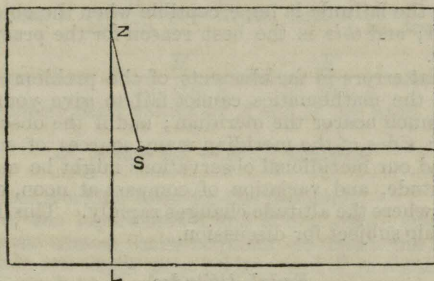
$$R = \cos. \text{ lat. } \cos. \text{ dec. cosec. mer. zen. dist. } \frac{2 \sin.^2 \frac{h}{2}}{\sin. 1''}$$

The following modification of it seems to offer some advantages:—

$$\begin{aligned} R &= \frac{\cos. l \cos. d}{\sin. z} \cdot N \\ &= \frac{\cos. l \cos. d}{\sin. (l - d)} \cdot N \\ &= \frac{\cos. l \cos. d}{\sin. l \cdot \cos. l - \cos. l \cdot \sin. d} \cdot N \\ &= \frac{N}{\tan. l - \tan. d}. \end{aligned}$$

This, with a table of nat. tangents and another of the values of  $N$ , gives the simplest mode of computing the reduction.

The following method of determining the latitude by projection on a Mercator's chart might be practised with advantage as a check to calculation:—



\* See Riddle's Navigation.

† The late Mr. Riddle communicated this method to the Phil. Mag. in October 1818, having practised it for a considerable time previous. It next appeared, I believe, in Brinkley's *Astronomy*, 1819, and again deemed original when published in 1821, by Gen. Sir Thomas Brisbane, in the *Edin. Phil. Trans.*



*S* position of the sun on its parallel of declination, according to the estimated Greenwich time. *LZ* the meridian of the observation, determined by its longitude. *SZ* the zenith distance, taken with compasses from the divided meridian, and applied from *S* to *Z*, gives the place of the observer at *Z*.

It is an old maxim in nautical astronomy, that observations for the determination of time should be taken when the object employed is as near as may be to the prime vertical. An error in the observed altitude then produces the least possible effect on the computed meridian distance.

The expression of the relation between these errors is—

$$E = \frac{A}{\sin. az. \cos. lat.}$$

or when the  $az. = 90^\circ$

$$E = \frac{A}{\cos. lat.}$$

It appears, therefore, that the latitude is an important element in this relation, and that the effect of an error of observation will be greater in high latitudes than in low ones.

For a place on the equator,

$$E = A,$$

and therefore under no circumstances can the error in the hour angle be less than the error in the observed altitude.

But an error in the observed altitude is not the only one to which the navigator is liable, neither is it the one to which he is most exposed. The skilled observer, with good instruments, can do much to guard against errors on his own part; and those whose observations are infected by bad habits, such as observing the limbs overlapped or open, may destroy their effect by taking alternately the upper and lower limb.

Besides, the sun is generally low when near the prime vertical, and therefore more subject to the variability of the refraction. Indeed, the error to which extra-meridional observations is most liable exists rather in the estimated latitude. The effect of any probable error in the latitude is imperceptible when the object is on the prime vertical; and *this* is the best reason for the practice usually recommended.

Provided that errors in the elements of the problem are avoided or destroyed, the mathematics cannot fail to give your time from observations much nearer the meridian; and if the observations are taken on both sides of the meridian many sources of error may be eliminated, and our meridional observations might be made to give latitude, longitude, and variation of compass at noon, especially in low latitudes, where the altitude changes rapidly. This I would still suggest as a fair subject for discussion.

#### *Equal Altitudes.*

Galbraiths says (see his tables), "When great accuracy is required, equal altitudes are very superior (to the common methods of finding time), especially when a transit instrument cannot be obtained. On this account various tables have been computed to facilitate this operation, though it is believed few of them afford great advantage

“in practice. By reason of the inconvenience of taking proportional parts, it is often better to give an easy practical rule, requiring the use of the ordinary tables, when neither double entries, different signs, nor proportional parts are necessary.”

This opinion is a sound one, and for a long period I have not allowed my pupils the use of any special tables for this problem.

Mendoza Rios's table of the equation of equal altitudes is one of a convenient form and good principle; the interval of time between the observations and the longitude of the sun being used as arguments. They do not, however, enable us to dispense with the logarithmic tables, and therefore afford no great additional facility to the solution of the problem, especially when the trouble of interpolation is taken into account.

Baron Zach also published tables for the same purpose. The most popular, however, are those of Baily, commonly known as Logs. A and B. Even these are open to objection, as depending on the change declination between the noon of the preceding day and the noon of the day following the day of the observation; a change in eight-and-forty hours—a period, perhaps, ten times that which elapses between the two observations.

This, perhaps, arose out of the circumstance that the daily change, or two-daily change, could be most readily obtained from the “Nautical Almanac” in its old form. But now that the hourly change of the sun's declination is given in the “Nautical Almanac,” it has struck me that a much more convenient system of tables might be devised.

My plan is this: the formula for the equation of equal altitudes is

$$c. \tan. \text{lat. cosec. } h - c. \cot. p. \cot. h.$$

When  $c = \frac{1}{2}$  change of dec. and  $h$  the hour angle;

$$\text{or, } d^1. \tan. \text{lat.} \times \frac{H}{\sin. h} - d^1 \tan. \text{dec.} \times \frac{H}{\tan. h}$$

$d^1 =$  hourly change of dec., and  $H =$  hours in  $\frac{1}{2}$  elapsed time.

$$\therefore c = d^1 \times H$$

Dividing by 15 to reduce the expression to seconds of time

$$d^1 \tan. \text{lat.} \times \frac{H}{15. \sin. h} - d^1 \tan. \text{dec.} \times \frac{H}{15. \tan. h}$$

Now the logarithms of  $\frac{H}{15. \sin. h}$  and  $\frac{H}{15. \tan. h}$  are easily tabulated; and denoting their values by  $A$  and  $B$ , we have

$$d^1. A \tan. \text{lat.} - d^1. B \tan. \text{dec.}$$

as the convenient working form for the problem.

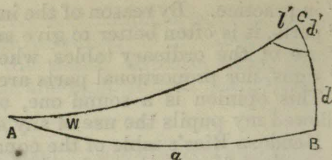
The tables of the logarithms  $A$  and  $B$  are small, and even when carried out to the utmost limits requisite to spare the necessity of any interpolation are single page tables; and  $d^1$  is obtained at once from the “Nautical Almanac.”

Indeed, the second term can be easily tabulated in a still more concise manner. This term never exceeds 3.3 seconds of time, and only attains this maximum value when the sun's declination is  $17^\circ$ , and the elapsed time between the observations at the smallest value ever employed.



This result being I believe, new, and its investigation curiously simple, I will give it here.

$$\begin{aligned} d' &= l' \cos. C \\ &= l' \cos. \alpha \sin. w. \end{aligned}$$



$$\therefore \text{ multiply by } \tan. d = \sin. \alpha \tan. w$$

$$d' \tan. d = l' \sin. \alpha \cos. \alpha \times \sin. w \tan. w$$

but  $l' \sin. w \tan. w$  is almost constant,

$$\text{and } \therefore d' \tan. d \propto \sin. \alpha \cos. \alpha \propto \sin. 2\alpha$$

$\therefore d' \tan. d$  is greatest when  $\sin. 2\alpha$  is greatest, or where  $\alpha = 45^\circ$ , and corresponding values in succeeding quadrants.

Whence  $d' = 17^\circ 3' 31''$ .

Next the maximum value of  $B = 10.82^\circ$ ; whence the value of the second term  $= 3.3^\circ$ .

#### Double Altitudes.

The simplicity of the computation of the correction due to the change of declination, as I have now given it, leaves nothing to desire, either in conciseness or accuracy.

$$\text{The correction is } c \frac{\sin. H^1}{\sin. H.}$$

$$\text{or, } d^1 \sin. H^1 \times \frac{\text{hours in } H}{\sin. H}$$

$$\begin{aligned} \text{When } c &= \text{change of declination in the half elapsed time,} \\ &= \text{hourly change } (d^1) \times \text{hours in } H. \end{aligned}$$

Now,  $\frac{\text{hours in } H}{\sin. H}$  may be taken as  $= 4$  within all the ordinary limits of observation.

Whence the correction  $= 4 d^1 \sin. H^1$ , the value of which may be readily obtained from the common traverse table.

The maximum value of this  $= 4 d^1$  and the greatest value of  $d^1$  occurs at the equinoxes, when it is nearly  $1'$ ; therefore the greatest possible error from neglecting the correction is 4 miles.

But in practice  $H^1$  rarely exceed 2 hours, which will make the extreme probable error about 2 miles.

Woodhouse's formula\* for the same correction is

$$\pm (D - d) \frac{\cos. \frac{a + a^1}{2} \cdot \sin. \frac{a - a^1}{2}}{\cos. D \cos. L \sin.^2 \frac{t}{2}}$$

This is strictly accurate also, and on making the reductions of which it admits, readily falls into the shape

$$\frac{\sin. H^1}{\sin. H}$$

\* See Woodhouse's Astronomy.

It is well to know the limits of error in this way, that we may be fully aware what degree of dependence to place on the results of our calculations if this correction should be omitted altogether.

The rule for its application is rather complicated, and depends on two considerations.

1. The relative magnitude of the two altitudes.
2. The increasing or decreasing of the sun's polar distance, or of the lengths of the days.

The following quaint artifice may serve at least to amuse you.  
The letters of the gentle word

#### M I L D

contain the initials of the words More, Less, Increasing, Decreasing.

When the second altitude is	More than the first,	} }	The correc- tion is +
and the days	Increasing in length,		
or, When the second altitude is	Less than the first,		
and the days	Decreasing in length,		

Therefore if the observation under discussion furnishes the initials *M* and *I*, or *L* and *D*, the sign is additive.

Otherwise the sign is negative.

#### *Lunars.*

With reference to the problem of finding the longitude by lunar distances, of which so many solutions have been given, I would urge that the direct calculation of the spherical triangles, involving only the common logarithmic tables, is the most satisfactory. The employment of special tables, with the view of making the work more concise, is often very deceptive, and a mere substitution of labour of one kind for labour of another kind; and the simple principles of the problem are always more or less obscured by them. The *few* figures may be, and generally are, obtained with more trouble than the *many*, and the simplicity is only in show.

Having now glanced at several of the leading subjects of astronomical navigation, and overstepped the bounds of the time allotted me, I must conclude with one more necessary piece of advice, that the use of nautical instruments be diligently practised and taught, for without this all your teaching is imperfect almost to uselessness.



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LECTURES  
ADDRESSED TO TEACHERS  
ON  
PREPARATION FOR OBTAINING SCIENCE  
CERTIFICATES  
AND THE  
METHOD OF TEACHING A SCIENCE CLASS.

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LECTURE X.

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ON PHYSICAL GEOGRAPHY AND  
ITS APPLICATION TO THE TEACHING OF  
GEOGRAPHY IN SCHOOLS;

DELIVERED AT  
THE SOUTH KENSINGTON MUSEUM,  
21st January 1861,

BY  
GOTTFRIED KINKEL, PHIL. D., F.R.G.S.,

FORMERLY PROFESSOR IN THE UNIVERSITY OF BONN, EXAMINER IN PHYSICAL  
GEOGRAPHY AT THE SCIENCE AND ART DEPARTMENT EXAMINATIONS  
OF THE MASTERS IN NAVIGATION SCHOOLS.



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PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.

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\* 1861.

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Price 2d.



“Geography, regarded only as the description of the outlines of the earth, and the determination by astronomical observations of the relative position of hills, rivers, and valleys, to be laid down by a topographer on a map, is but the keystone of that splendid science when viewed in its most comprehensive bearing.”—SIR RODERICK I. MURCHISON, *Address to the Geographical and Ethnological Section of the British Association at the Oxford Meeting of 1860.*

## LECTURE.

In the course of lectures addressed to teachers, on the method of studying and teaching the different branches of science, it has fallen to my share to speak on *physical geography*, and I do not believe that any of the lecturers who preceded me, has been trusted with a more attractive subject.

The principal charm of physical geography rests upon the fact that it is quite a new science, and therefore has all the vigour of a fresh branch. The first man that conceived and sketched out the system of a complete view of the universe was Alexander von Humboldt, who left this scene of his earthly labour but two years ago. Thus physical geography is a science only coeval with our own generation, nor could it have been otherwise. Physical geography is in all its branches a result of discovery; its laws are a generalization from facts which had to be established, compared, and connected, before you could construct them into a system. It was not until the whole globe was known and mapped out, that you could speculate on the laws of the division of land and water, on the form of the continents, on the direction of ocean currents, on the distribution of plants and animals, or the difference of isothermal, isotheral, and isochimenal lines. Now it is not fully a century that the island world in the Pacific and the great continent of Australia were opened to investigation, and as there are even now regions not disclosed to our curiosity, and every day adds new facts to the mysterious life of our globe, the science of physical geography is still in full growth. This growth, in fact, is so rapid that any author on physical geography, if he wishes to keep up with the pace of investigation, will be bound actually to re-write his book at least every 10 years, and that the very best physical atlas becomes antiquated even in a shorter time.

I am the last man to deny the exertions and successful issues of antiquity in the field of natural history and descriptive geography; and I believe that whatever, in these branches, could be done 1,800 years ago, has honestly been done by Pliny, the naturalist, and Strabo, the geographer. But, clever and valuable as many general conclusions of these and other ancient writers are, the portion of the world within their ken was much too small to allow of their arriving at general results. Remember that Herodotus, who, for his time, surely was a great traveller, with a wonderful eye for observation, never set foot in the tropical world, except in one spot, on the confines of Egypt and Nubia; where, however, owing to the barrenness of that particular region, he could not be impressed with the beauty and fertility of the tropics; consider that even to Tacitus, half a millennium after Herodotus, the Shetlands and the amber coast of the Baltic were the extreme limits of traditionary knowledge towards the polar regions; and keep in mind that, leaving alone America and Polynesia, even the gigantic world of China was unknown, to the very name, to any European before the Christian era, whilst never a ship left the coasts and sailed on the high seas, except by favour of the Indian monsoons; take these points together into consideration, and you will at once understand why even the idea of physical geography could not dawn in the mind of antiquity. As to the middle ages, they were surely given up to speculation, but, on the whole, very indifferent to observation and discovery, and besides became even more impoverished in general geographical knowledge than antiquity, since the rising power of the Islam cut off the intercourse



of Christian Europe with India and Africa. To remove this barrier of ignorance, to open new oceans and fresh countries, and to found a solid system of natural philosophy, was the task of the 15th, 16th, and 17th century. You certainly could not speak of the very rudiments of physical geography, before you were sure that the earth moved round the sun, and this became known or at least was acknowledged but three centuries ago. It is our duty now to draw the results of all these discoveries, to generalize the millions of observations, and to reduce the facts to a system. Just this is the task of the physical geographer.

Another great attraction of our science is its central position amidst all other branches of human knowledge. First of all, physical geography draws the results of all the different branches of natural science. From *mathematics* and *astronomy* we obtain the solution of all the great problems of mathematical geography. We borrow from *physics* the laws by which the two great oceans surrounding our globe, the aerial and the watery, regulate their life. For the investigation of the earth's crust and its formation in mountains, plains, and table-lands, we must draw on the storehouses of *geology* and *mineralogy*. The flora of the globe connects physical geography with *botany*, the fauna with *zoology*; and the races of man can only be discerned and classified by the assistance of *ethnography* and *anatomy*. Thus far physical geography is a summary of results drawn from all natural sciences, and there is hardly any discovery to be made within the empire of nature that will not in some way or other influence our study or our teaching of this wonderful branch. Yet, here too lies its difficulty. The majority of men have a talent for specialty. Specialty can be learnt by memory, without the imagination of the poet or the genius of the philosopher; but generalization is a power limited to the few, for a greater number of people like to cram than to think; and I verily believe that physical geography is so much neglected in our public and private schools, because it obliges the teacher to generalize, instead of showing off his knowledge in the detail.

Yet, comprehensive as may appear this connexion of physical geography with its sister sciences of nature, it opens a prospect no less wide and infinite into quite another range of human knowledge. If you attempt to draw a broad division of all sciences, you will see that they separate in two grand masses, the one being the science of nature, the other the knowledge of the human mind and its results in politics, art, science, literature, industry, and commerce. Geography, in its widest sense, is the connecting link of both masses. Its two first branches, mathematical and physical geography, fall entirely on the side of nature; its third branch, political geography, lies on the side of the human mind. For be it at once stated what separates these three great branches of geography. Mathematical and physical geography show the globe as the hand of nature framed it; political geography tells us what man made of it. Thus physical geography connects the science of nature with the science of the human mind. Without it history can never be understood. If I describe Australia physically, I must fall upon the fact, that this continent, before Europeans settled there, contained no animal that could be domesticated for the use of man, for giving milk or meat or assisting in labour at any time the owner required it. Surely it would be hard work to tend a flock of 1,000 opossums, nor should I like to drive a plough with a pair of kangaroos; so it is easy to show that the poor blacks in Australia could not even reach the low degree of civilization which the very negro of Africa has attained by his ox and sheep. But what is worse, Australia has no grain what-

ever, no fruit that can be converted into flour and bread; and so its inhabitants were doomed for ever to remain savage hunters and fishermen, without the possibility of tilling the ground and forming civilized communities. Now I will confess I do not belong to the school which deducts the destiny of a nation merely from the structure of the country, and the fertility of the soil. This is barefaced materialism in science. Just as in an individual it is mind and body that, operating together, work out a man's life as their common result, so it is not merely the country, but also the race that produces history, for good or for evil. In California the gold existed from the days of old; there was that splendid harbour of San Francisco, and the gigantic Wellingtonia rose in the valleys, before man set his foot under its majestic shade. But for centuries had the benighted Indian, the bigoted Spaniard, possessed the country without finding a single nugget, without sending a single keel out of the Golden Gates; and not ere the sharp eye, the active mind, the strong arm of the American seized upon this western paradise, did California rise to its immense historical and commercial importance. So you see there is much in the race; without that wild roamer upon the seas, the Dane, or that bold adventurer, the Norman, would neither the Briton with his indifference to the salt water, nor the Anglo-Saxon's peaceful skill in husbandry have made England what she is now, the queen of the ocean and the mistress of distant empires twenty times her own size. Yet we must, on the other hand, not deny the important fact, that our mind is never independent of our body, and that in any region, where nature shows herself a step-mother to her son, no moral or mental power can overcome the impossibilities thrown in the way of progress. Amongst Greenlanders and Esquimaux Grecian art will never flourish; no Hindoo will ever write a rational work on history; and no nation without a sea coast will twine a wreath of colonies around her head. Thus we see, that an eye capable of reading the great hieroglyphics inscribed by the finger of nature as mountains and river valleys in the face of the earth, may decipher in these great tablets many a grand page of history.

If I now venture to offer a few hints as to the method of studying physical geography, I believe I can do no better than lay before you the results of my own experience in teaching it. For 10 years I have now been teaching and lecturing on this science in England, and, I must confess, I had to begin under great disadvantages. Geography, as it is usually treated in schools, is considered by the pupils a great bore, and the consequence of this is a general neglect of the study. Perhaps, on no point are people in this country more ignorant than in geography, and the school books mostly in use show a deplorable want of method. It is certainly a strange fact, that Britain, although she rules over one-fifth of the human race and girds all oceans and continents with her dominions, colonies, and naval stations, has not established a chair for geography in any of her universities or larger colleges for genteel education.\* Thus

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\* I am not exaggerating. Great Britain has produced Captain Cooke, Sir John Franklin, Dr. Livingston, Sir Roderick Murchison. She has a Geographical Society, to which every scientific traveller turns for information; in no country an equal annual number of books of travels are published; never in world's history did a colonial empire like hers exist. And there is no chair for geography at Oxford, Cambridge, Edinburgh, at King's College, or University College, nor even an examiner on geography in London University. The country which practically, like none other, promotes the study of geography, completely ignores geography in its scientific teaching.



surely geography is not a favoured subject with the leaders of our education, and England generally ignores the world which she governs. However, I have succeeded in gathering audiences round me, and difficult as physical geography may appear, I have expounded it several times, even to children from 10 to 15 years of age, and riveted the interest of my audience. So, whatever my scientific acquirements may be, I have a right to consider my method successful, and may be allowed to turn my own experience to the benefit of my colleagues in teaching, for if we know how to teach it, we shall at once see how we must study it. Now there are two ways of expounding physical geography; first, by itself, then in connection with political geography.

As to the first of the two, there can be no doubt about the arrangement of the science and its division in chapters. On that point all the systematic writers on our subject, Humboldt, Mrs. Somerville, Klöden, agree, and all the smaller manuals follow the same plan.\* I will not enter upon the disputable point, whether mathematical geography is an essential part of physical geography or a branch of its own. For the practical use of tuition, at all events, you cannot do without it. You must begin with contemplating the earth as part of the universe. Your pupils will at once be attracted, if you promise to show them how the seasons follow each other, why their relations in Australia celebrate their Christmas with green peas and cherries, and how by way of latitude and longitude a sailor is able to reach with certainty the smallest island lost in the immensity of the Pacific; for you should always fix your theoretical instruction to some practical question, which rises spontaneously in the minds of your young audience. On mathematical geography, however, I will not say anything special; this branch, owing to the general interest in number and calculation inherent in the English mind, is well treated in English schools. Those of my audience that are likely to come before this committee for examination, will know mathematical geography from its utility in navigation; and the use of the globes, which is nothing but the practical application of mathematical geography, has formed for many years an integral and legitimate part of school business.

The next point will be to divide your subject in two halves: the inorganic and the organic bodies, of which the connecting link is the theory of the climate. I usually begin with placing a map of the whole world with the two hemispheres before the pupils, in order that they may learn *how to read a map*. This is an important point. Most people do not understand maps, nor are they able to gather great facts from the mere view of the map. Yet a well directed look at the map of the world reveals a great number of interesting subjects. The land is wide to the North, and narrows to the South. Take a globe and turn it so that the Bay of Biscay comes up as the centre of a hemisphere. In this simple way you can show that Great Britain lies in the centre of the greatest amount of continent, whilst it is round the island of the Antipodes that the largest possible oceanic hemisphere, with the fewest and smallest portion of land, expands. From this you can make your audience comprehend the important commercial situation of their own native

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\* For the examinations for Science certificates, the work of Mrs. Somerville, and the "Outlines of Physical Geography," by Edward Hughes (late headmaster of the Royal Naval Lower School, Greenwich Hospital), are proposed as text books. A teacher who knows the contents of the latter book well will be able to pass; a candidate, who has thoroughly studied and *digested* Mrs. Somerville's work, will be able to obtain a good predicate.

country. Further, the continents appear all pointed to the south, and in that direction all great peninsulas stretch: yet the north of the continents, too, rises towards the pole under nearly the same meridians as their farthest expansion to the south; so the rising of the continents must have been in some way connected with the direction of the meridians. Continue then by comparing the continents; let your pupils understand how Europe, with her immense coast line, with her jagged shores broken into innumerable gulfs, islands, and peninsulas, invited the foreign settler, and became the foremost country in civilization. Show then how Africa, being inaccessible through the massive bulk of her outline, warded off the foreigner and remained mentally behind the other sisters. Explain the easy migrations of nations from Asia into every continent, whilst the southern lands, scattered amidst gigantic oceans, could not attempt a civilizing intercourse with each other. Let your young people see how Asia, in every one of her extremities, assimilates her physical features to the adjacent continents; how Asia Minor resembles Greece; how Southern Siberia, passing imperceptibly into Eastern Europe, became the highway of Nomades into the Black Sea regions; how the Esquimo found in America the same climate which he had left in the north-eastern peninsula of Asia; how the Arab was brought up to expand his national life and creed, his date palm and camel, into the deserts of Africa, so singularly similar to his own native sand; how the tropical world of India is continued through a long south-eastern train of islands across the whole Pacific; how, in a word, mother Asia, before sending forth her different children from the threshold of home, first inured them individually just to the very same hardships which each of them would encounter in the country of his choice. See what a quantity of interesting observations you can at once derive from a mere outline map and the distribution of the continents.

Having thus impressed on the mind of your audience the general form of the continents, the crust of the earth comes next. It must depend upon your own knowledge of the subject, how far you will enter upon geology; at all events, I would classify the principal rocks and illustrate them with specimens from the neighbourhood. Here is the place, too, to speak of the mineral productions of the earth, as far as they minister to the wants of mankind, and if you are in a mining district, there will be neither lack of specimens nor of attraction. Volcanoes are always very striking to the young mind; describe some of them in a graphic and animated way, and then deduct from these descriptions the laws of volcanic action and of earthquakes. Take your pupils out for a walk over hill and dale; make them understand what a valley, a slope, a table-land means. Take a thermometer with you, and show them the difference of temperature in a level near the sea and on the top of a mountain; walk up a stream to the source, then up a tributary brook, and thus show them what a river basin is. When you come home, let them draw maps of the ground they walked over with you; let them paint the levels in green, the hills in brown, the flat backs of the hills and the plateaux, if there are any, in white, and draw in the brooks and rivers with black or blue ink; where there are swamps, pools, or ponds, let them draw them likewise in blue. One such map, drawn from the observation of the pupil himself, is worth more than a hundred of those copied maps, of which certain schools boast, and which in reality have no value at all, as they are mere mechanical, or at best, mnemonic work. For having once drawn his own parish upon the principle of a physical map, your



pupils will henceforth be able to read a physical map, and besides, they will attend to the physical features of any part of the world they go to. So now you may take your physical wall map and teach them the details, tracing the great mountain groups, tablelands, plains, and deserts. Show them how they can determine from the map whether a promontory is a bold headland or a low ness. Measure the length of your brook, and by transferring this measure upon the Nile, Yantsekiang, or Amazon, give them a vivid impression of the extent of other continents. Explain to them how America, sealed to the west by the mountains, opens her plains and river outlets towards Europe and attracts the European settler; how Asia, sterile in her centre, stretches to the sea the glorious fertility of her levels; and how Africa, built up in terraces, prevents the foreign vessel from sailing up to her centre. If in this way you know how to generalize, your pupils will at the same time be most willing to learn the detail in the bargain.

Next to this will come the theory of the oceans, and hydrography in general. No chapter in our science is more charming than this to an English child; the sailor blood comes out the moment you mention the salt water. Measure before their eyes the depth of the neighbouring stream, and then tell them of the depth of the high seas; make them understand that Great Britain and the islands around stand upon a submarine plateau; that St. Paul's church, when placed in the English channel, would, in most places, stand out with its dome like a tiny island; and that the real basin of the Atlantic, our true separation from the western continent, only begins a hundred miles from our western shore. The colour, salt-ness, and temperature of the ocean can in so many places be illustrated by showing and measuring them in reality; and the great phenomenon of the tides will weigh on the mind of every inhabitant of the shore, until you give him the solution of the problem.

After the oceans, lakes, and rivers, we come upon the great aerial sea surrounding our globe. Here you reveal to your audience that wonderful circulation of water, which has its parallel in the blood of the animal organism. From the ocean, as the heaving heart of the universe, by evaporation the cloud rises; it returns to the earth by precipitation, and in the thousand veins of rills, streams, and rivers, returns to the common centre of life. The clouds in their different shape; the feathery cirrus, the dazzling cumulus, slowly floating along in the blue noonday sky, the stratus of the night resting like a wall over the northern seas,—are they not in themselves a never exhausted source of interest and observation? The various kinds of precipitation by mist, rain, hail, snow, and dew, upon which all the fertility of the soil depends, must become attractive to the cottager's child, when you reveal their causes and conditions, as the sailor boy will be charmed, when you open his eye to the origin and influence of the various winds. You improve humanity if you make men understand the things upon which their earthly existence rests.

From meteorology you have but one step to climate, and this subject again forms the bridge for passing from the inorganic half of your science to the organic part. The productions of the soil in the vegetable and animal kingdom, and at last the races of men, constitute this part of our subject. Here a double way lies before you, and you have the choice: Either you may walk through the single continents, and speak of the mammalia of Asia first, then of those of Europe, then of Africa, America, Australia. The birds, reptiles, fishes, insects, will follow in the same order, and the plants accordingly. Or you will do as the botanist and naturalist

does; you will classify by genus, family, species, leaving the geographical arrangement subordinate; that will depend on your greater or lesser knowledge of these special branches. But, above all, dwell upon those gifts of the earth which are useful to man, and let us hear from which parts of the world we obtain the principal necessities, commodities, and ornaments of life. Commercial zoology and botany will prove more exciting and useful than a scientific system of floras and faunas. In the present state of the world the division of labour has led to a remarkable ignorance about labour. The children of the cockney know that they can buy the fig, date, and orange in the grocer's shop at the next corner, provided they coax their twopence out of mamma; beyond that grocer's shop their imagination does not range. It is pitiful to observe how ignorant people are about the places where things come from, even the sellers themselves.\* Now here lies a capital means of waking a warm interest. Do you know what the real gift of a teacher is?—That he should develop the unknown from what is known; that he should find the hook already extant in the pupil's mind on which to attach a new thread of thought. Here lies one of these hooks, by which you can attract even the youngest children, if you will inform them wherefrom tea, coffee, rice, tapioca, come, how they are planted and prepared for use. Tell your audience how almost all our fruits, the peach, apricot, lemon, cherry, and grape, originally came from Western Asia, and reveal to them the profound meaning of the verse in Genesis, that it was in those parts that God planted the garden with all the different fruit trees. Show them how our ox, horse, ass, and camel descend from the same parts, from Western Asia, and open in this way their eyes to the great historical fact of the great migrations from our common father's house, Asia.† And then spread before them the table of races of man. That's another point shamefully neglected in our education, and this neglect has bred that truly European contempt of our brethren in other continents, and destroyed justice and charity in our dealings with them. It seems as if the English, from their insular position, had become singularly indifferent even as to the races and nationalities in Europe, just at a time when the very principle of coincidence of nationality and state (may we like it or not, the fact exists,) is growing into the principal lever of political changes; and from this indifference comes the total ignorance about the real political questions of the continent, an ignorance so pitiable to every foreigner when he reads the pretentious leaders of the great London journals. And having thus concluded the division and description of the human races, considering them as the last productions of the earth, it is here that Physical Geography ends. “A physical

\* At the examination held by this department on Physical Geography, one question is regularly given, asking for the countries where our principal imports grow; and it is singular to observe that this question, in a country so essentially commercial as England, but too often proves a stumbling block to the candidate.

† There are three public collections in London and its neighbourhood, which will be a great help to the teacher, where the connexion of trade and commerce with the productions of the three natural kingdoms comes into question. They are the Museum of Practical Geology, in Jermyn Street; the Museum of Practical Botany at Kew; and the Museum of Animal and Vegetable Productions and Manufactures at South Kensington. All three are so admirably arranged that, with a merely an observant eye, within a short time the subjects for a whole lecture, systematically composed and ready for use, may be collected there.



“ picture of Nature,” these are the words with which Humboldt closes the first volume of his *Kosmos*, “ points out the boundary “ where the sphere of intellect commences, and a distant view into “ another world opens. It points out the boundary, without “ passing it.”

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We, however, must pass this boundary, for, as I already stated, Physical Geography is not only a complete system in itself, it also lends its powerful aid to the instruction in political geography, and as here is it of the most efficient use, I will conclude with some observations on the manner in which it should be applied. Let me confess at once my sad conviction that almost everywhere geography is taught in a wretched way. Being considered a portion of what is called the “ English branch ” of education, (one hardly sees why it should be more closely connected with English grammar, than, for instance, music is), it is in families and schools thrown to the governess. Of course, a governess, as the scholastic advertisements in the *Times* will show you, must understand English, French, German, Italian, besides a bit of Latin, and, if possible, Hebrew—music, to be sure, and singing. Now that is more than the most profound scholar could undertake to teach. But she must besides teach history and geography. Poor girl: so she takes a text-book and makes the poor children learn by heart what neither they understand, nor, of course, the governess herself. Never mind, there are at the end of every chapter the questions and answers! So the children of our gentry and nobility go on, they learn the 34 States of Germany with all their capitals, and all the 86 Departments of France with their *chef-lieux*, and then come the Counties of England and Wales, of Scotland, and then of Ireland (they are the worst!). That’s what they call geography, the rack of the nursery, the bore of the school, the despair of children, the yawn of the teachers, the wicked destruction of memory, for it is a falsehood to say that memory is strengthened by a million of indifferent and confused lines scratched into it. Every teacher that lays the pains of learning on the shoulders of the pupil, *instead of taking upon himself the pains of teaching*, let him go and tend pigs instead of children! Every learning is useless which is not connected with ideas, and everything we forget that is not riveted to our mind, either by logical development or by imagination. Now I declare, when you begin to teach geography with the political part, you can neither proceed logically, nor awaken the imagination. You cannot paint a picture without a background. It is impossible to make any pupil understand the state of a country, if you have not first described to him the country itself. This is almost entirely ignored in our school teaching. How totally indifferent people must be on this point is proved to me by the circumstance that amongst the hundreds of wall maps published annually in London, there are not ten physical school room maps extant, except Sydow’s, and they are of foreign manufacture; and then some relief maps, and people tell me that they are no longer published, because they would not sell. That shows what it is; we want teachers that understand how to teach geography; and it seems we have them not, else there would be a demand for physical maps, and if there were a demand, either science or speculation would soon produce a supply. The common political wall maps are abominably false as to the physical features. As everybody knows, the two islands of Great Britain and Ireland contain no table-lands, except the small ones in Cornwall and Devonshire,

and as this form of elevation is not familiar to the inhabitants of these islands, all English maps blot out the table lands from every continent.\* In all the wall maps I know, even those published by societies, Spain appears like a lowland, only intersected by chains of hills; the Norwegian Alps, drawn as a narrow ridge, are on either side surrounded by flats, and in Asia, Tibet, with its elevation of 13,000 feet, looks quite as low as Bengal on the southern side of the Himalayas. It is, indeed, impossible to draw the physical features of a country clearly on a political map, as the coloured lines of the boundaries and the large number of states, provinces, and towns, prevent an accurate drawing of the physical features; and it is just for this reason that separate physical wall maps, by the side of political maps, are indispensable.† Take, for instance, Sydow's or Johnston's physical maps of Europe, and look what the world really is; then you will not see the three southern peninsulas all lowland, with thin snaky lines of mountains crawling over them like a scolopendra,‡ but with mountains decidedly in preponderance over the flats, and each peninsula in the sharply defined drawing of her bony parts: Spain, like a block of rock with a few splits: Italy, a serpent with a backbone without ribs: Turkey and Greece, like a leaf with veins shooting forth from the central stem. If in this way, with the assistance of a good physical map, you individualize a country *by explaining its skeleton*, you have at once gained that clearness of conception which an artist gains by studying the skeleton of any animal he wants to represent.

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Now to show how physical geography in the description of every individual country should be connected with the physical part, it would be best, if you could prevail on the Council of Education that they allowed good teachers to give, instead of lectures, one lesson each before the preceptors, as if it were before a school; for the

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\* "The common method in describing the earth is open to the same reproach as many Histories. As the latter over the eminent heads forget the hearts, and over the princes the people, so Geography, frequently in favour of the high peaks, neglects the base which connects and supports them."—Carl Ritter, *Erdbeschreibung*, vol. i. p. 94.

† Once a governess (and not a particularly stupid one), showed me a new atlas, and said with enthusiasm, "I like this atlas; the maps are so clear; *there are so few mountains on them.*"

‡ There is a serviceable physical wall map of the British Isles, published by the National Society; also several good geological maps of the same isles. But it was only last year that a distinguished British cartographer, Mr. Alexander Keith Johnstone, commenced a series of physical wall maps on the continents, of which the first, Europe, is out, and an excellent and highly finished map it is. The only *complete series* of physical wall maps is Sydow's, originally published in Germany (by Justus Perthes, Gotha), of which an English edition, with a short English book of reference, is on sale at Messrs. Williams and Norgate's, Henrietta Street, Covent Garden. They are large and very clearly drawn; the physical map of Europe is a true masterpiece of cartographic skill. Most of the cheap *political* wall maps generally used in English schools are below criticism. Those published by Philips and Son are, however, recommendable for a fuller indication of the physical features. They are drawn by Mr. William Hughes, (late Professor of Geography in the College for Civil Engineers, and now at Queen's College), whose "Manual of Geography, physical, industrial, and political," (London, Longman, Brown, Green, and Longmans), in two parts, is, of all English books I know, by far the best in point of the physical foundation of political geography.



practical application by example would teach an audience better than any theory. As it is, I can only by a rapid glance at one country show you, how in teaching geography, one thought should spring from another, and all appear connected into a living picture, and not merely a piece work, or at best a mosaic. Let us take a country just now particularly attractive, Italy. Here I would first describe the Alps, and explain how and why they divide four nationalities; in their eastern part, where they grow wide and low, so that the railway from Vienna to Trieste could be laid across them, the German element, and the territory of the German Confederation, with Trieste, cross the mountain barrier. I would then sketch Lombardy; the northern lakes, in the deep splits of which the Alpine streams are filtered; the great artery of the Po, with the network of its hundred canals and its rice swamps, its lower course lying 40 feet higher than the market-place at Ferrara. Why was this Lombardy made to become the garden of Europe? The Apennine would follow; its calcareous eastern range; its volcanic western hills. I would mention how barren the one is, how prolific the other; why in the former the wolf still exists, whilst the west coasts of Italy, having plains and rivers, became successively the seat of so many great empires. I would describe the marble of the Apennine as the material for Italian high art; its flocks, as feeding the dairy and the factories; its volcanoes, malaria, and earthquakes as the drawbacks to the southern splendour of life and landscape. Why is Italy so warm? Why did she become the nursery garden, through which eastern fruit became acclimatised in Europe? And when and whence were cherry, apricot, peach, orange, and date palm first planted in her soil? How did the enormous silk industry of Italy grow, and what is this industry worth at the present time? Then comes the race of men: Italy, with her three islands, is about the size of Great Britain and Ireland taken together, and notwithstanding her monastic institutions, her bad government, her internal wars, with her 26 millions of inhabitants, is only 4 millions below the British Empire, which now for more than a century has been free of all those hindrances; so, surely, the Italians cannot be a nation of idlers, if they are able to maintain a population so dense in comparison with Spain and Turkey. Which were the ancient elements of the Italian nation; the Ligurian, Gaul, Etruscan, Latin, Greek? and how was the Roman blood tempered by the German and Arab immigration in the middle ages? What are the physical, mental, and moral qualities of the present Italian? Why did Italy take the lead in some branches of Art? Then, after this general description has been given, I would enter upon the political state of things; explain the former weakness caused by the division in small states and the consequent influence of the foreigner; dwell upon the present concentration, and finally describe the single towns of note in a lively way.

Poor and incomplete as this sketch must be for want of room, you will perhaps gather from it what we propose. Give us, in one word, connected thoughts instead of loose detail; description for enumeration; facts for words; and instead of smothering memory with the weight of dead matter, appeal to the imagination. I said before that the ancients were not able to form a system of physical geography; but in the description of single countries they had already found the right method, and the more shame for us that we should have lost it again. Take, for instance, Herodotus; read his second book on Egypt, and if you do not understand Greek, why read it in Mr. G. Rawlinson's translation. See how he starts from

the soil, explains the fertility, describes the Nile, and collects the traditions about its sources; how he brings in all knowledge at his command about the shape of Africa, and the travels of discovery made around and within it. Having thus spread his canvas, he now proceeds to sketch the Egyptian race, their political system, their arts, burials, religious ceremonies; and having thus accomplished the geography and attracted us to his subject, he now proceeds to give the history. Or go to the two works of Tacitus that contain descriptions of two northern countries: his *Germania*, and his book on Great Britain under the title of *Agricola*. There you may learn how to draw an interesting and well-arranged picture of a country, its climate, productions, and men. Why, it is wonderful to read: there are actually but two short chapters on the geography of Great Britain, and what a treasure of invaluable information do they contain! That the Scotch are taller, and frequently have red hair, that the Welsh have a darker tint, and the hair more crisp, that the Britons in Kent were relations to the Gauls; that our skies are dark, but the climate milder than on the continent; that, and why, our crops come out early and yet ripen late; the long day of summer in the Orkneys; that capital observation on the British character, that the Briton is willing to obey, provided you show him no injustice,—here you may learn how to look out for matter of observation, and how to weave it into a beautiful carpet of tuition. And if you want a modern book of the same power, but at the same time full of the science of our own era, read Humboldt's travels in America, and see how there, by the side of the most philosophical investigation of nature, the most amusing views open on every side upon the reality of life, on the habitations of the Indians, on caverns full of curious birds, on the earthquake of Carracas, on the milk tree, on the plantation of the coffee and cocoa, and the state of the Spanish colonies in general. Indeed, if you ask me at the end of this lecture, where shall we find the material for so extensive a range of knowledge, I will answer frankly, not, of course, in your poor text-book, but *in the books of travel*. England has not yet succeeded in writing a general work on the whole of geography, such a one as France has in her *Malte Brun*, and Germany would have had, had Carl Ritter lived long enough to finish the first of all geography books in the world. But although in English literature no system of geography exists, your literature is wonderfully rich in tourists and travellers. The old Norman propensity of rambling in foreign countries, the love of sport in wild regions still full of game, the necessity of long stays in lonely stations and distant colonies, and, above all, the enormous movement of the British commerce, has brought Englishmen, Scots, and Irish into almost every corner of the world, and opened their eyes for observation. Many of these books of travel, of course, are trash; if an ignorant clerk writes a book on his continental tour, hoping to get his travelling expenses back from the publisher, or if a high-born lady complains of every raw dinner or every flea-bite in an Italian inn, we cannot learn much from them, and he would better have remained behind his counter, and she in the midst of her comforts, with German maid and French cook. But besides such trash, there is an enormous amount of sterling observation in the better books of this class, and it is wonderful to see how lively you can draw your pictures when borrowing the palette from the eye-witness. Nor is this branch of literature likely to dry up. This is a marvellous time for the geographer, teeming with great and long-sought discoveries. The north-west passage is now explored,—a Scotchman has crossed Africa right through, from west



to east,—a few months ago, Mr. Macdougall Stuart planted on a rock in the very heart of Australia, in the centre between W. and E., N. and S. coast, the Union Jack of England; and this very year of 1861 will at last disclose to us the mysterious source of the Nile, for which three millenniums have longed in vain. It is a delight to live in such a century, and shame on ourselves if we are indifferent, and keep our children indifferent to the blessing of living in it.

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Council on Education.

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# LECTURE

ON THE

## PROMOTION OF SCIENCE INSTRUCTION BY THE DEPARTMENT OF SCIENCE AND ART;

DELIVERED AT

THE SOUTH KENSINGTON MUSEUM,

4th February 1861.

BY

CAPTAIN DONNELLY, R.E.,

INSPECTOR FOR SCIENCE.



LONDON:

PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,  
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.

1861.



General and Art Department of the Committee of  
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1881

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## LECTURE.

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I HAVE been directed to give a lecture this evening on the "Promotion of Science Instruction by the Department of Science and Art," comprehending the nature and amount of assistance afforded.

It will be my endeavour, then, to explain to you, as clearly as I can, the general principles on which State aid is given, through this department, in the diffusion of scientific instruction, and to state generally what is the amount of the payments made to science teachers, (for that is really the main point,) and the manner in which they may be obtained. I need not enter into details; these are given in the "Directory" which is published by the department, where the few rules it is necessary to observe are given. But as these rules are merely dry instructions—sign-posts showing you which is the correct road, and every here and there cautioning you not to trespass to the right or to the left—my object is to explain the reasons why such and such a road is indicated; why such restrictions are imposed; what is the goal to be arrived at; in fact, to fill in the outlines; and, as the comparative anatomist rehabilitates from a few bones an extinct animal, clothes it with flesh and life, and shows the terms of its existence, bringing the living animal before the mind's eye, so it is, I take it, for me to endeavour to give some kind of life and unity to this system, to enable you the better to understand the rules. And this is rendered necessary by the fact that though the Science and Art Department has been in existence for many years, since 1852, during which time it has had numerous science and navigation schools in connexion with it, the present system is comparatively new. The first minute of the new system was passed in June 1859, and since then it has been developed, and the conditions of grants towards scientific instruction reorganized and placed on a new and distinct footing.

But before proceeding further, as I see among my audience many who *are not*, and are not likely to *become*, teachers, I may at once distinctly state that this is not a subject likely to be of general interest. The first demand on a lecturer is to make his subject popular and generally interesting. To do so he must have a sympathetic, or perhaps I may say, an audience personally interested in his subject. This may be my case; I shall be very glad if it is. But I am afraid that the title of my lecture may have deceived some. It is no portion of my duty to give any opinion on science generally, the method of teaching it, or the desirability of doing so. What I have to say to you is on the administration of an educational system, addressed to those whom it does more directly concern, the teachers. They, I console myself with the reflection, must be either more or less than human, if they do not take an interest in what explains the method by which they may, if not exactly make their fortunes, at all events do something in that direction. The "monetary intelligence," which fills such a conspicuous portion of the daily intelligence, the state of the funds, of railway shares, &c., is deeply interesting to those on 'Change, to those who have money to invest,



or shares to realize; but to the great mass who have no money to invest, no investment to realize, it can hardly be of interest, unless it be to deduce from it, as a pulse, an indication of the state of health of the nation. And this recalls to me that there is one other portion of society, a portion, I am proud to say, larger in England than, perhaps, in any other country in the world, whom my statement may interest—that large number of persons who devote their time, their money, and their labour to the improvement of their poorer fellow countrymen, in that best of all ways, by education.

And now, having run up my true colours, I cannot be charged with sailing under false ones, so I will proceed with my subject.

And first, I must explain what constitutes the Department of Science and Art. It is like many other institutions in this country, a consolidation and enlargement of what already existed when it was created in 1852. I need not trouble you with any lengthy statement about these several institutions, as they have been already explained by Mr. Cole, the secretary and general superintendent, and Dr. Lyon Playfair, the then Inspector-General of Science Schools, in addresses on the functions of the Science and Art Department, delivered in 1857, and since published. I may mention, however, that the oldest institution in connexion with this department is the Royal Dublin Society, which since 1800 had been in the receipt of a parliamentary grant, but was not under parliamentary control. The collections now in the museum in Jermyn Street commenced in 1835 with the Geological Survey; they were gradually increased, and a School of Mines having been organized in connexion with them, the whole were placed under the Board of Trade in 1851.

The Royal Dublin Society, the School of Mines and Geological Survey, the Museum of Irish Industry, the Industrial Museum of Scotland, and the Committee of Lectures in Dublin, were consolidated with the Department of Practical Art into one department, under the Board of Trade, in 1852, when Mr. Cardwell was President. It was then called the Department of Science and Art. Provincial schools of art were first established in 1837. The first attempt to establish provincial schools of science was made in 1853.

In 1857 the Department of Science and Art was formed into one division of the Committee of Council on Education, and was to be charged with the duty of offering increased means for promoting secondary or adult instruction; while the other, a separate division at Whitehall, continued charged with the functions of primary education.

The Department of Science and Art is now administered under the ministerial control of the president and vice-president of the Committee of Council on Education.

In 1859, when Lord Salisbury was president, the minute of the 2nd June was passed. It forms the basis of the present system of aid to scientific instruction. It is embodied, with the modifications which have been introduced into it from time to time, in the Science Directory.

The minute of the 14th July, when Lord Granville was president, with two minutes lately passed, one an interpretation minute on the minute of the 14th July, give the system of aid now granted to navigation schools. A directory will shortly be published giving further details as to navigation schools; but the system is very simple, and can be readily understood from the last two minutes, when taken in connexion with the principles of the Science Directory.

The Department of Science and Art is now the constituted machinery for giving State aid to certain branches of instruction—instruction

in art, of which I need not speak further, and instruction in certain definite subjects of science. I shall presently have occasion to state more precisely what these subjects are, but I would wish to call attention now to the fact that the aid is confined to certain definite subjects, and cannot be given to adult instruction generally. The list of subjects may be increased, or it may not. It may be increased so as to include very elementary instruction, in mathematics, for instance; but at present it does not, and therefore it is useless to urge, as is constantly done, that adults of the working classes, having left the elementary school when very young, are incapable of availing themselves of the instruction in which aid is afforded; or, in the form in which applications constantly appear, that such and such a subject, which bears directly on a subject specified, is of great assistance to the right understanding of it. Will an examination in it count for anything? All that can be said is, that nothing more or less than what is specified can be considered, and that we may be thankful for what we have got. At the same time, with reference to those subjects which bear on, and are, as it were, preparatory to the sciences specified, it is evident that, though not directly, they are indirectly aided by the assistance given to the more advanced branches of instruction; while it must be remembered that elementary adult instruction is partially met and assisted by the night schools, or third attendances of the elementary schools under the Education Department.

Before proceeding to explain the manner in which State aid is granted to scientific instruction, I may be permitted to glance at the question of the State granting aid at all, or official interference, as it is viewed respectively by the unwilling tax-payer and the out and out supporter of the voluntary system. I cannot attempt to enter fully into this subject. Indeed, one of the first writers on political economy, Mr. John Stuart Mill, has so ably shown that education is one of those things which a government is justified in providing for the people, and that help in education is help towards doing without help, and favourable to a spirit of independence, that it is quite unnecessary for me to say anything on the general question; but I think the most superficial consideration clearly points out the necessity for such help to science, the limits of the interference, and the manner in which it should be exercised, and may perhaps aid us in understanding the rules of the Directory.

I do not wish to enter on the much vexed question of the relative merits of science and other subjects as branches of education. It is a question which has been fully discussed by the ablest men. In the very course of lectures of which this is one, it has been touched upon by Professor Huxley. That instruction in science is *good* as a branch of education in its broadest sense is admitted by all; that it is the *best* means for the development of the mind, though, perhaps, not held by all authorities, is certainly held by an increasing number, and few will deny that it is the best form of education for that large mass with whom we are now principally concerned, who have not time to pursue their studies, classical studies for instance, to any extent. For science, but more particularly experimental science, has the advantage of classics and other studies in this, that sound information in science, however limited in extent, opens a field for thought and reflection, which classics (though I must not be considered as depreciating them) cannot do till after severe and long continued application; and further, this field for thought is so intimately connected with their daily labour, that instruction in it must prevent their going on in ignorance of the principles of their daily



work, and thereby losing one of the highest enjoyments of intellectual beings, the constant employment of their reasoning powers and of their understanding. There is another reason for the promotion of *scientific* instruction, it may be a narrow or a low view of the object of education, but, nevertheless, it is a valid one for the assistance of the State, and that is the great extent to which industry at the present time is dependent on science. The results of all human labour must depend on a correct application of the laws of nature. These may, and often have been correctly applied, without any knowledge of them in the abstract; that is, they have been employed empirically. But in the present day when science has opened to the world a knowledge of many of these laws, we cannot trust to an uncertain empirical knowledge; success in competition depends more and more on a correct knowledge and application of the laws which science teaches us, and our being the first in the field to take advantage of each new discovery. I need give no illustrations of this. Dr. Hoffmann, in his lecture a few weeks ago, showed some of the numerous results that the advance of one science alone, chemistry, had produced. Sir John Herschel has stated the case very forcibly,—

“ If the laws of nature, on the one hand, are invincible opponents, on the other, they are irresistible auxiliaries; and it will not be amiss if we regard them in each of these characters, and consider the great importance of a knowledge of them to mankind:—

“ I. In showing how to avoid attempting impossibilities.

“ II. In securing us from important mistakes in attempting what is itself possible, by means either inadequate or actually opposed to the end in view.”

“ III. In enabling us to accomplish our ends in the easiest, shortest, most economical, and most effectual manner.”

“ IV. In inducing us to attempt, and enabling us to accomplish, objects which, but for such knowledge, we should never have thought of undertaking.”

It is but the overflowings of abstract science, as has been well remarked, which enter into and animate industry, and no higher authority for the advantage to a State of cultivating such abstract knowledge can be quoted than Mr. Stuart Mill:—

“ In the national or universal point of view the labour of the savant or speculative thinker is as much a part of production, in the very narrowest sense, as that of the inventor of a practical art; many such inventions having been the direct consequences of theoretic discoveries, and every extension of the knowledge of the powers of nature being fruitful of application to the purposes of outward life. The electro-magnetic telegraph was the wonderful and most unexpected consequence of the experiment of Oersted, and of the mathematical investigations of Ampère; and the modern art of navigation is an unforeseen emanation from the purely speculative, and apparently merely curious, inquiry of the mathematicians of Alexandria, into the properties of three curves formed by the intersection of a plane and the surface of a cone. No limit can be set to the importance now, in a purely productive and material point of view, of mere thought. . . . Intellectual speculations must be looked upon as a most influential part of the productive labour of society, and the portion of its resources employed in carrying on and remunerating such labour, as a highly productive part of its expenditure.”

But it is not sufficient that some few of the nation should have a high knowledge of science, while the rest are sunk in ignorance, even if such a state of things were possible. The greatest stimulus is afforded by a wide diffusion. As the tree throwing out its branches



far and wide, receiving nourishment from the air, is still dependent for a portion of its sustenance and its stability on its roots being wide spread and deeply fixed below, so, to be healthy and vigorous, scientific information must more or less pervade all grades of society; for, as Mr. Buckle has shown, in his *History of Civilization*, the changes in a civilized nation, or its relative status, depends on the amount of knowledge possessed by its ablest men, on the direction it takes, and above all, on the extent to which this knowledge is diffused, and the freedom with which it pervades all classes of society.

The savant confining himself to abstract science makes his discoveries and gives us a knowledge of the laws of nature; he is, in many cases, unacquainted with the details of manufacture, or is heedless of them, and, therefore, cannot improve them. It is for the men practically engaged to avail themselves of these discoveries. The richer few, I own, are able to, and should provide themselves with this instruction, but to the many this is impossible. "It was," said Lord Brougham, in his inaugural address to the University of Edinburgh, "a pupil of this university (Birkbeck), afterwards transferred to a quasi-collegiate chair at Glasgow, who, 60 years ago, made the first step of lecturing upon scientific subjects to the working classes. In the town where Watt in his workshop applied in philosophic principle the knowledge he had learned from Black, to the construction of the great engine which has almost changed the face of the world, the attempt was most appropriately made, and with complete success, to demonstrate that the highest intellectual cultivation, and a keen relish for the sublime truths of science, is compatible with the daily toils and cares of our humbler brethren."

Acknowledging, then, the importance of a diffusion of a knowledge of science, an importance so great as to justify an interference of the Government, if the means for diffusing it have not already been furnished by voluntary effort, the question arises—what has been done during these last 60 years? I should certainly say not much, though I am fully aware of the many efforts which have been made by local institutions and by societies, such as the Society of Arts. These efforts have, however, been but partially successful and very restricted. The results keep no pace with the requirements of the times, but, on the other hand, we are falling behind the nations of the continent and behind America in our means of giving scientific instruction to the industrial classes. I need only refer you to Dr. Lyon Playfair's pamphlet on industrial instruction on the continent, to show what was being done there 10 years ago. If it were likely that voluntary effort would or could do much in this direction, I should certainly say let it do so without State interference, but the experiment has been tried long enough without success, and on the other hand the people, and the tax-paying portion of the people more especially, have become loud in their application for Government assistance, as was shown by the numerous petitions from the large manufacturing towns presented after the Great Exhibition in 1851, quoted in the Second Report of the Royal Commissioners. There are few, I imagine, who do not think that this assistance will be more ably and judiciously applied by a central authority, responsible to Parliament, than by local authorities and vestries; but, at the same time, as it would be monstrous for the government of a free country (whatever it may be for a paternal government) to become the apostles of science or anything else, however convinced the members of that government might be of its advantages, so it is evident that the aid should be supplemental to, and not taking the place of voluntary and local effort, avoiding thereby the errors of continental systems, where the State takes the leading and dominant part in education.



These considerations point very clearly, I think, to the best mode of State interference.

And first, we may say that State aid should be confined to giving instruction to those who cannot provide it for themselves, but are dependent on those above them, and when the latter, failing by voluntary organization to provide it for them, are willing that Government should step in and aid. At the same time the richer classes who pay for such instruction should be allowed to avail themselves of it, and encouraged to do so; for, State aid forming no part, as it were, of their payments, their larger fees to the teacher will tend to render the system self-supporting.

Secondly, the aid should be given in such a manner as to afford the maximum of assistance with the minimum of interference—interference never amounting to dictation, but simply to securing the honest application of the funds granted. For two reasons, first, because there must always be a tendency in a governing body to twist the convictions of the governed to their own convictions. Whilst, as was said by Mr. Harry Chester, in a speech to the United Association of Schoolmasters of Great Britain, “A government ought to represent ‘the results of the education of a well-educated people, the ‘education of a people ought not to take its tone and character from ‘their government.’” And, second, because interference is an expensive article. In order to interfere effectually, it is necessary to have a large staff who somehow or other absorb a great deal of money, and we know what the effect of burning the candle at both ends is.

Thirdly, the aid should be granted on an elastic system, if I may so term it,—a system such that, without breaking faith, the aid may be gradually lessened, and even eventually withdrawn, when the necessity for it ceases. The demands for scientific instruction are now small, liberal aid may be afforded without its being an appreciable burthen on the public purse. This is likely to stimulate, and it is to be hoped rapidly increase, the amount of scientific instruction. It would be absurd to expect the country to support the proportionately rapidly increasing demands, which it must do, if the system were inelastic. No, as the demand increases we may naturally expect that the system will become more and more self-supporting, requiring less and less cockering up by State aid.

And lastly, the central machinery should be the smallest possible, every endeavour being made to utilize, and by that means educate local and voluntary effort, not only to save expense but also with a view of its eventually assuming its own responsibilities.

I consider this elasticity one of the great advantages of the present system, for I believe the great objection there is in Parliament and the country generally to the establishment of any new drain on the public purse for however deserving an object, arises from the well-grounded apprehension that in a moment we may be committed to an immense and increasing expenditure, when any attempt at retrenchment is met with a cry of hardship and vested interests. Now, in any system in which the scale of payment is fixed, and dependent on fixed conditions, the payments must increase as the area of the fulfilment of conditions increases. We all must hope for the speediest and greatest extension of education in any form, but looking at it as tax-payers, we may not hope for a proportionate increase of payments. When the conditions are fixed, however, there can be no way of retrenchment with justice; we must either, continuing our aid to those who have already obtained it, say we will assist no others, or by restrictions in the form of vexatious regulations deter further applicants, and this is palpably unjust; some



will have all, and some, depending wholly on accident, nothing ; instead of the aid being divided among all according to their deserts.

It follows, then, that the conditions should be what I have termed elastic ; and I believe I shall be able to show that the terms of the directory are such, that supposing the development of Science instruction to be very great, and the expenditure to rise proportionately high, if at any time it was decided that there should be no further increase in the expense, in fact, if the country thought it was paying enough for science, and that we should stop at that point, say, 10,000*l.* per annum, that 10,000*l.* might still be divided with the greatest nicety and justice year by year over an increasing area, simply according to deserts. Perhaps some of my hearers, looking at it with the eyes of future receivers (which I hope they may be), and not as income-tax payers, may not exactly see the beauties of this power of retrenchment. But I think even they will acknowledge them, when they see the consequent non-necessity for hampering restrictions.

I have thus far quitted my rôle as explainer of an administrative process, and trenched, as perhaps you may think, on the province of the statesman, not with any view of announcing a new discovery of my own, but to make clear to you the rules of the directory by explaining beforehand the spirit which runs through them—the reasons which led to the conditions assuming the form they do.

And now to come to the rules themselves. The first point is the subjects which are aided. These are :—

- i. Practical Plane, and Descriptive Geometry, with Mechanical and Machine Drawing, and Building Construction.\*
- ii. Mechanical Physics.
- iii. Experimental Physics.
- iv. Chemistry.
- v. Geology and Mineralogy.
- vi. Animal Physiology and Zoology.
- vii. Vegetable Physiology, Economic Botany, and Systematic Botany.

The subjects are again divided into subdivisions for the convenience of teachers and pupils.

And besides these, for the Navigation schools specially, there are mathematics, navigation and nautical astronomy, and physical geography. The Navigation schools have certain peculiarities. I shall, therefore, recur to them again presently, confining myself at present to the Science schools and classes proper.

There are but two ways in which aid can be given to effecting any object, either directly by aiding *in* its accomplishment, or indirectly by rewarding *for* its accomplishment.

Now remembering that our object is to aid in the simplest way the efficient teaching of certain sciences, that is to produce the taught article, having more regard to the advantages of the taught than to those of the teacher, the readiest method that suggests itself is to pay for the result. When we want any ordinary article, clothes, for instance, of a particular quality, we pay a sufficient price for what we require and let the producer take care of himself, knowing very well that if we make it worth his while he will provide us with them, or in fact that the supply will keep pace with the demand. Well, if this department were to apply the same principle and pay so much, a fair price, for the article required, viz., artisans with a certain knowledge of science to be tested by an examination, I have no doubt, in

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\* Naval Architecture may be taken instead of Building Construction.



a longer or a shorter time, depending on various circumstances, we should have what we require. For instance, if 1,000*l.* a year were offered for a certain number of good chemists—of course fixing the requirements within reasonable limits—I have no doubt they would soon be forthcoming. This is the process at present employed for obtaining Science teachers—barring the amounts offered—with what success I shall presently tell you.

This very free trade process is, however, not carried to its full extent in the *teaching*; the state of the labour market required a small tincture of protection. The teacher who can receive payments for the taught pupils must be certificated as qualified to teach by possessing a sound knowledge of some of the before mentioned sciences. I need not trouble you with the various reasons for this restriction, but it is evident that it is not very oppressive, and on the other hand has the advantages of to a certain extent ensuring the results, however limited, being sound, and therefore easily tested; and, further, of providing the country with some criterion of the capability and trustworthiness of the instructors, to whom, of course, this certificate is of proportionate advantage. But the great principle on which all payments are made, that of paying on proved results alone, is still adhered to. For besides enabling the system to be very simple, this has the great recommendation of drawing out the energy of the teacher. It is astonishing how much better the generality of people work when they know that they will be rewarded proportionately to their exertions, than when their rewards are fixed, and they are left more or less to themselves to fix the proportion of work due.

When I say, then, that the department grants certificates, and that these certificates carry with them certain certificate allowances, it must be clearly understood that nothing is paid on faith. These certificates merely carry with them the authority or qualification to earn Government money up to a certain amount, under easy conditions, conditions easier than those under which other sums unlimited in amount may be earned.

To carry out these principles the department holds, in November of each year, an examination of all persons who choose to come up and try for certificates either in one or more of the subjects, or in a subdivision of a subject only.

These certificates are of three grades, 1st, 2nd, and 3rd class, each certificate entitling the holder to earn, under the head of certificate allowances, 20*l.*, 15*l.*, or 10*l.*, according to its grade, that is, if the certificate is for a whole subject, and half that amount if in a subdivision only. Thus, supposing A.B. has a 1st grade certificate in chemistry, and a 1st grade certificate in experimental physics, he is qualified to earn 40*l.* under the head of certificate allowance. This he may earn by teaching a class chemistry or experimental physics, or both.

In order to determine the results of teaching, the department holds in May in each year examinations in the various sciences at all places in the kingdom, where there are classes presenting themselves for examination.

For every pupil of the artizan class who passes such an examination as to justify the examiner in reporting that his instruction has been sound, and that he has benefited by it, the teacher receives 4*l.* of his certificate allowance.

The artizan class is broadly defined, as including all who are in the receipt of weekly wages, and their children. For others who, receiving payments at longer intervals than a week, may still from the smallness of their income be justly entitled to the same benefits,



a special application must be made by the Committee of the School, as you will see from the Directory.

The pupil, on account of whom payment is claimed, must have received 40 lessons at least from the teacher, not necessarily all in one year, but since the last examination at which payments were claimed on his account.

The examinations which are held simultaneously all over the kingdom are distinct in each subdivision of the subjects before given, that is each subdivision will be taken separately.

Taking the case of A.B., who is qualified to earn 40*l.*, supposing he has one class which has been taught inorganic chemistry, on a certain evening in May it will be examined: if 10 or more of his pupils passed, he would receive the whole of his certificate allowance, 40*l.*; if only six passed, he would receive 24*l.*, and so on, 4*l.* per passed pupil up to the amount he is qualified to earn by his certificates; for the amount that he may receive under the head of certificate allowance is limited by the value of his certificates; however, many of his pupils pass, A.B. cannot receive more than 40*l.* under the head of certificate allowance. But this is not the only way in which he may earn payments. This condition, easy of fulfilment, is to stimulate him to increase his knowledge, to induce him to work for and obtain certificates of the highest grade, by making a portion of his reward depend on his personal acquirements as distinct from his success in teaching, whilst there is another condition not so easy of fulfilment by which he may earn amounts only limited by his success in teaching.

The amount he may earn altogether by successful teaching is not limited by his certificate allowance or in any way by the rules.

For every one of his pupils of the artizan class who takes a Queen's prize, that is, shows a knowledge something above the mere *pass*, he receives 3*l.*, 2*l.*, or 1*l.*, according to the grade of the prize, over and above anything he may receive under the head of certificate allowance.

Thus, supposing A.B. had passed 10 or 15 pupils, and that six of the had taken first class Queen's prize, he would receive 40*l.* + 18*l.* = 58*l.*; or to take an extreme case, supposing he had not been able to collect a large class, but had taught one artizan very well, that he was examined, and took a first class Queen's prize, A.B. would receive 7*l.*, 4*l.* of his certificate allowance, and 3*l.* payment on Queen's prize.

I think I need not give any other illustrations, for I hope these, with the cases given in the directory, will make the rules clear. You will see also from the directory that in the case of a Science teacher who holds a certificate of the Education Department, the value of this certificate is added to the value of his Science certificates, and the amount earned in the same manner.

The amount that a teacher may earn, then, under the head of certificate allowance is restricted, but there is no restriction as to the whole amount which he may by ability and hard work obtain.

I will now pass on to the Queen's prizes and rewards to students.

There is no restriction as to the class of persons who may obtain them. Any one may come up to the examinations, not merely those who have been receiving instruction from the certificated teacher, but outsiders of every class. Indeed, it is made a condition that the committee of a Science school or class shall provide a room for the examination of every one who wishes to be examined; and, as they may be placed at some expense in doing so, they are permitted, if they think fit, to charge a registration fee of not more than 2*s.* 6*d.* for all outsiders.



All who pass a creditable examination, will receive, according to their merits, Queen's prizes of the 1st, 2nd, or 3rd class, consisting of books of different values, according to the grade of the prize. These prizes are not given in competition, but depend, like the certificates of teachers, on certain standards of proficiency being attained. And, as I before stated, for all Queen's prizes taken by artisans taught by the certificated teacher, the certificated teacher receives 3*l.*, 2*l.*, or 1*l.*, as the case may be. He receives no payments for prizes taken by other pupils, nor does an uncertificated teacher receive payments for any pupils of his of the artisan class who take prizes: but the prizes themselves are open to all.

I have now gone through all the conditions and the manner of obtaining the aid of the department, except that the school or class taught by a certificated teacher, and on which he claims payment, must be open at any time to the visit and inspection of the officers of the department, that they may see that there is a proper room, &c. provided for the instruction of the class, and that the apparatus, diagrams, &c., towards the purchase of which the department pays 50 per cent., is kept in proper order. I shall have to speak of the apparatus grants again.

To return to the examinations. Besides the Queen's prizes there are in each subject six medals offered for competition among all the classes. The medals are one gold, two silver, and three bronze, which will be given to the most successful candidates in the examination, if the standard of attainment is such as to justify the examiners in recommending them.

As the examinations in each subject will be held simultaneously all over the kingdom, it is necessary to call in local agencies to give their assistance, for it is evident that the department could not furnish officers to conduct or superintend examinations in fifty or perhaps a hundred different places (as I have no doubt before long there will be) on one night. The committees of the schools are entrusted with this duty. The examination papers prepared in London by the examiners will be forwarded to them, they will see them worked, and return the worked papers to the department for revision, three, at least, of the committee certifying to their having been present and seen them fairly worked.

By this means not only is a great saving effected in the machinery of inspection and examination, but a great step, which it is expected will not be abused, taken to decentralize the system, and by calling on local exertion for assistance, and trusting to it to create and keep alive an interest in the subject. At the same time one examination provides the tests for passing, for Queen's prizes, and for Queen's medals.

The department calls on the committee also for further assistance.\* As soon as the results of the examination are made known, the certificated teacher fills up a form of application for salary, with the names of the successful pupils, on whom he claims payment. The committee then certify to the claim on the two points of the teacher having given the students 40 lessons at least, and of their being artisans or operatives, or their children of above 12 years of age. As soon as these lists are verified, the teacher receives his payments.

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\* The relations of the teacher to the local committee are not defined by the rules of the directory. But it is left to circumstances of the locality to determine whether the teacher engaged by the Committee should be their servant, or on the other hand whether the teacher, having established the class, gentlemen in the neighbourhood merely aid him by acting on a committee.



There is also another form of assistance granted by the department, and that is in the purchase of apparatus, diagrams, text-books, &c. Aid is given to the extent of 50 per cent. on the cost price.

This aid is not restricted to the schools and classes taught by a certificated teacher any poor school may obtain aid, but only to the extent of 5%.

The apparatus, &c., on which aid is claimed must be that contained in the lists furnished by the department. Some of the apparatus, such as the models prepared by the Messrs. Rigg, and many of the diagrams, as those of Professor Henslow for botany, Mr. Marshall's for physiology, have been prepared at the suggestion of the department, but they are published through the common channels of trade. There is no assumption of the duties of the tradesman. Except to a very limited extent, the department does not constitute itself the judge of the description of apparatus, but in no case does it take upon itself the responsibility of saying which maker's is the best. All manufacturers are allowed to compete under certain restrictions which you will see in the directory, and the decision or choice rests with the applicants. The main condition on which manufacturers compete is that they furnish specimens for exhibition in the Educational Museum with priced catalogues which may be furnished to applicants. The deposited specimens then serve as samples by which to judge of the quality of the articles supplied; and, being collected together in the Museum, enable teachers and others readily to compare them and make a selection. All the invidiousness, and indeed injustice, of a Government Department fixing on one particular manufacturer is thus avoided. These conditions have but lately been made public, but you may see in one of the bays of the Educational Museum the chemical apparatus which the Messrs. Grif have already sent in with an admirable illustrated catalogue. I believe the Messrs. Elliot and other manufacturers are preparing collections and catalogues with the same object.

I have now sketched briefly the outlines of the directory. It is unnecessary for me to trouble you with details which you may readily find for yourself, though in reality I believe there is scarcely a rule which I have not touched on, for it is one of the advantages of the system that, few checks or restrictions being required, the code may be very brief.

The directory, which many of you may have, appears to contradict my statement, but that is only because it contains a detailed syllabus to guide the reading of candidates for certificates as teachers, as also the examination papers which have been set. And I may here remark that this syllabus is also meant as a guide to the teachers in the instruction of their classes.

The papers which were given at the doors contain, I may say, all the rules. They were printed in that form for the almanac, and I have had them extracted because the present edition of the directory has all been distributed. The new edition is now in the press, and contains some changes in the syllabus consequent on the late division of the subject of natural history, which was formerly taken as one subject with two subdivisions, into two subjects or four subdivisions.

It will soon be ready and can be then obtained on application.

If teachers, and gentlemen on committees too, will allow me to give them a piece of advice in studying the directory, I would say to them—read it as it is, and with the aid of Johnson's Dictionary, if necessary, take the words in their ordinary meaning. This may



seem absurd, but I can assure you that if they had done so many letter writers would have saved themselves a great deal of trouble. Many questions that are asked show so evidently that the inquirer had made up his mind as to what he thought the rules must be before reading them over, if he ever condescended to do so, and then wrote to ask his way out of difficulties which his foregone conclusions alone had created. Numbers of instances might be mentioned. The words religion, sect, denomination, are never even mentioned, nor is there the slightest indication that there are any such tests or restrictions; and yet a few days ago the question was asked whether the fact of a teacher's pupils belonging to a certain denomination was not a bar to their being examined in chemistry. Again it has been asked whether theoretical mechanics might not mean algebra and trigonometry, and so on. In fact, generally, whether one thing does not mean another.

Thus far many of my audience may think I have been developing a very fine theory; a theory, however, which depends on improbable, if not impossible, conditions to become a working reality. These conditions being whether a demand does bring forward or can ever create a supply of the article required—that is of competent teachers of science; and if it can, whether the inducements now offered are sufficient, and the terms of such a nature as to create a real demand,—whether, in fact, we are not asking for bricks without supplying the straw, while it is impossible for the brickmakers themselves to find it.

I am glad to say I can give a satisfactory answer—that it appears that the straw is to be had and the reward is sufficient to induce the brickmakers to find it for themselves. It must be remembered that I am not enunciating a perfectly new theory. It is a system which has been tested experimentally, and I believe you will agree with me with great success, a success which the most sanguine could not have expected.

In June 1859 the first Minute was passed; though successive additions and modifications have brought it into the shape of the present Directory, the main points—the certificate allowances and examination for certificates in November—were contained in it. No attempts were made to circulate it very widely, and indeed it was not till very shortly before the first examination that the syllabus of subjects could be prepared, and it was considered desirable not to press the matter forward, but to wait and take advantage of the experience afforded by the first examination. Nevertheless, in the following November (November 1859) 57 candidates came up. There were 104 entries for subdivisinal certificates (there were then only 11 subdivisions of subjects); 43 candidates were successful and 65 subdivisinal certificates taken,—14 first grade, 20 second grade, 32 third grade. This last year (1860) 89 candidates came up; there were then 13 subdivisions of subjects. And there were 170 entries for subdivisinal certificates; 75 candidates were successful and 121 subdivisinal certificates were taken,—22 first grade, 44 second grade, 55 third grade.

Though the terms of the directory are scarcely yet known in the country, you see there were a considerable number of candidates at the first examination, and an increase of nearly 60 per cent. at the next—in one year. There are now 106 teachers certificated under the new system. Many of the candidates who came up to the last examination had come up to the previous one; some had failed, others came up again to improve their certificates, clearly showing that there was sufficient inducement to tempt them to work and



qualify themselves or improve their certificates. A large proportion came up for the first time, and some of these I know had done a good deal towards working up their subjects since the first announcement; and, judging from applications, I believe there are many now preparing themselves for next examination. But of course it must be a work of time—of years—for any large number of persons who may be induced to turn their attention to it to qualify themselves. But the experience of the last examination shows that there *is* that inducement, and the result of the first examination more especially shows that, what with training colleges and what with other institutions, there *is* a means, however limited, of obtaining scientific instruction without the creation of a special training class; and that there are a number of persons who, by availing themselves of these means and by private study, have already qualified themselves for teaching, and to whom it is only necessary to offer certain inducement to make them turn their attention to teaching Science.

This does not prove that we have all that is necessary to create an efficient staff of Science teachers, and I should be the last person to underrate the value or necessity for special training or scientific instruction of the highest class, more especially in some of the subjects which it is next to impossible for a man to teach himself by reading books or to obtain instruction in; and I hope and trust that means may be sanctioned for meeting this want. The professors at the School of Mines in Jermyn Street have already done a great deal by organizing courses of lectures in certain subjects with special view to assisting teachers in preparing for examination. These lectures have been very well attended, and I am convinced they will be of immense benefit; but at present, of course, it is only Londoners who can attend them.

What I do think the statistics I just now gave you prove is that there is sufficient machinery to be obtained in the present state of things to commence with. And before Government can do any good by aiding in specially training science teachers, we must have a sufficient constituency to support them, which at present there is not. That is to say, I am convinced that if the training of teachers had formed the main channel of aid to scientific instruction for the industrial classes, this attempt would have failed as previous attempts did,—for this reason, when a teacher has been specially trained he naturally expects to make his livelihood by giving scientific instruction and by that alone. Now, at the present time, there are very few places where he could do this,—none where he could do so by his own exertions,—and it would remain for the State either to let him go about his business,—a great hardship, besides the waste of money spent in training,—or, on the other hand, the attempt must be made to give him employment by stimulating some kind of Science school into an unhealthy existence, and by giving the teacher large payments in faith for some years, with a kind of faint hope that he may, almost against his own interest, exert himself so as eventually to do without it.

I am not developing this out of my own self-consciousness. The following extract from Dr. Playfair's lecture will show that I am right:—

“I will take the case of the Potteries School of Chemistry as an illustration. It opened a year since with numerous pupils, under a guarantee for one year of a certain amount of fees by the manufacturers of the district. The health of the master unfortunately gave way, and he had to leave suddenly. The working men



of Stoke, Hanley, and Burslem apply for a new master, and register a large number of pupils. A master is sent down to make inquiries, but finds that the aggregate of their fees is only 46l., and that there are no higher paying pupils in the district. He naturally refuses to accept the school at a remuneration which, including the certificate, would not amount to 100l. per annum, and under our present mode of action no more can be given. The meritorious desire of the working classes in the Potteries to learn the science bearing on their trade cannot be gratified." A teacher under the present system having other occupations besides science teaching would be very glad to commence on this footing.

The fact is, that *under the present circumstances of the case*, about the only portion of the day during which he can be engaged in giving instruction in science, at least such instruction as this department is justified in paying upon, that of the industrial or poorer classes, is the evening. It is a well known fact that the children of artisans are taken from the elementary school when they are very young and go to work during the day. Whether any remain till they are old enough, and whether any or what science they might or should be taught in elementary schools (I mean such as are under the inspection of and receive aid from the Education Department, Whitehall), I have nothing to do with, for I am not now discussing science instruction in general, but in particular as connected with this department. One of the regulations is that schools or classes must receive aid wholly from either one or other of the departments and not from both; and further, for reasons which you will see in a memorandum on the subject given in the directory no special payments for science instruction in elementary schools are allowed, as it is considered that the time and work of the teacher in the elementary school is sufficiently remunerated.

But to return, it follows that the only directions in which a science certificated teacher can look to earn his payments is in evening classes for adults held in Mechanics' Institutions, Athenæums, and such places, to a certain extent in schools not under inspection of the Education Department, and in special schools of the nature of trade schools. To these latter I shall revert presently.

With respect to the evening classes, the main dependence at present, you will soon see how the system works, even though there is not sufficient employment for the specially trained teacher. Any one may come up and take a certificate; he may be a working artisan having his day occupied, and turning his evenings to account in giving instruction in science, he may make a very acceptable addition to his income, besides being a most acceptable teacher to his own class. (I am glad to say we already have certificated teachers of this stamp.) Or he may be a clerk in a merchant's office, or a teacher in an elementary school, who not having pupil-teachers apprenticed to him, has his evenings to himself and turns them to account in this way. These last are perhaps the largest class of certificated teachers, and they possess the great qualification of being accustomed to teach.

To all such the science instruction gives an addition to their ordinary income; they can be content with small, very small, beginnings, even classes of 4 or 5, or 1, for the matter of that.

It is different with the specially trained teacher; he can hardly be expected to commence two trades at once. There is not a large ready made science constituency to support him, and he might starve before he had formed one. This constituency will be stimulated and developed much better by the resident teachers of the



class I have spoken of than by specially trained men sent down and supported by large grants while doing so.

That there will be such a development in time as will support teachers in many places while only giving scientific instruction I anticipate with great confidence. For even admitting that at present *all* the children of the working classes are removed from the elementary school before they are old enough to learn any science, I believe the real reason was given by Lord Stanley when he said "the school teaching of the boy has no connexion with the "after life of the man. Without a well-considered-system of instruction for youths and men, the school system, by which children only are taught, remains imperfect and almost useless, an ample foundation, but left without a superstructure." The early demand for labour is a strong inducement, and no wonder it is given way to, when there is no counteracting inducement. When the parents themselves, when artizans, study in the evening classes, and see the advantages that their children may obtain by remaining longer at a day school, where the instruction is carried on to something that will be of daily application, I believe it will be otherwise; and the experiments tried at many places bear me out.

In existing elementary schools not receiving aid from the Education Department classes of the more advanced boys can of course be formed at once under a certificated teacher, and, if not from them alone, between them and the evening classes for adults, he may readily obtain his allowances. Such is the case in the Glasgow secular schools. There are about 200 boys and girls in the school altogether, who receive a certain amount of instruction in science that is to say, it is systematically made a means of education. Physiology has been taught in this way for some time. The head teacher in this school, Mr. Mayer, obtained a certificate in chemistry at the examination in November 1859. In the June following, when I inspected the school, 12 of the best pupils in chemistry came up for examination; all but 3 passed, and 6 obtained Queen's prizes.

But there is also another class of school which I believe in time, as the industrial classes of the country become more impressed with the advantages of scientific instruction for their children, will be greatly multiplied, and will not only give employment to science teachers, but be of great advantage to the country: I mean the trade schools, schools something beyond the ordinary elementary school, taking the children of artizans and small tradesmen when they have learnt to read and write and cypher, but not till then, and giving them a special or technical education if they please; but at all events an education far above that of the ordinary elementary school. Of these schools Canon Moseley and Canon Richson have long been great advocates. A school of this nature, the Bristol Trade School, which Canon Moseley was mainly instrumental in establishing, is at present doing very well. The inhabitants are becoming fully alive to its benefits, and many free apprenticeships have been given in competition among the pupils by the manufacturers of the neighbourhood.\*

\* In Dr. Lyon Playfair's Introductory Lecture in the "Government School of Mines," for the Session 1852-3, is a full report of the state of industrial instruction on the Continent. In Prussia we find there were 26 provincial trade schools, feeders to a central institution containing about 170 pupils, to which the best pupils of the provincial schools have the privilege of passing and receiving gratuitous instruction in all the information that may be required by a person engaged in any of the productive arts. They are not admitted "unless they are well acquainted with the elements of mathematics, physics, chemistry, and drawing." For admission to the provincial schools, the pupils "must have had a good primary education in his own language, must thoroughly understand the elements of arithmetic, and the mensuration of plane and solid bodies, and must be able to show that he is a good free-hand drawer."



The great administrative difficulty with them, and what has in fact caused their failure in all cases, except the one before mentioned, in which they have been tried, is this, that being for boys, it is necessary to combine elementary with the science teaching; in fact the greater portion of the instruction is, or ought to be, elementary, unless the boys come well prepared.

Now this Department cannot recognize or pay for elementary instruction. If the funds of the school are not sufficient to take charge of the elementary instruction unaided it is very likely to go to the wall. But science cannot prosper at the expense of reading and writing. When the attempt was made some years ago to establish trade schools the rules were perhaps rather lax as to the Department not aiding elementary instruction; in fact, it was not very clearly defined what subjects were to be aided. Now the rules are very stringent. Still I believe, when the industrial classes see the advantages to be gained by it, but not till then, will they send their children to these trade schools for a few years after they leave the elementary school. Through them the teachers will be enabled to earn the aid of this Department. But again, what advantages these schools may offer to tradesmen and that large class who are perhaps the worst off for education for their children of any? By paying higher fees they will do much to keep up the school. And how much better for them the instruction they may then get than what they get now? Is it not ridiculous to prepare a boy for looking after, perhaps eventually superintending machinery, by making him learn the Latin grammar by heart?

As Sidney Smith puts it, "Cicero, in his Offices, tells a whimsical anecdote of Cato the Censor. Somebody asked him what was the best mode of employing capital? He said, to farm good pasture land. What next? To farm middling pasture land. Well, but after that, what the next? To farm bad pasture land. Now, the notions which prevail in England respecting classical learning, seem to me to resemble very much those which the old Roman entertained with regard to his favourite method of cultivation. Is a young man able to spare the time necessary to enable him to pass through the University. Make him a good classical scholar. But a second, instead of residing at the University, must go into business when he leaves school. Make him a tolerable classical scholar. A third has still less time to snatch up knowledge, and is destined for active employment while still a boy. Make him a bad classical scholar. If he does not become a Porson or a Heyne, he may learn to write nonsense verses. If he does not get on to Horace, he may read the first book of Cæsar. If there is not time for such a degree of improvement, he may at least be flogged through that immemorial vestibule of learning, *Quis docet*: who teacheth? *Magister docet*: the master teacheth. Would to heaven that he taught something better worth knowing."

I have given one case of a Science class having been established by a teacher certificated under the provisions of the directory, and that was the chemistry class in the Glasgow Secular School. Several others have been established, viz. in Edinburgh, Gloucester, Banbury, Dedham, Halifax, Huddersfield, London (at the London Mechanics' Institution, Chelsea Athenæum, Barking Athenæum, Lambeth, Poplar, Highgate), Manchester, Slaithwaite, Hollinwood, Painswick, Bristol (a mining school, independent of the Trade school), Haslingden, and other institutions in connexion with the East Lancashire and Cheshire Union of mechanics' institutions, and in classes in connexion with the Miners' Association of Cornwall and Devon. These are independent of the few classes, or schools which were in

existence when the Minute of 2nd June 1859, was passed. There may be many more, I believe, than are, now being established, but the system of non-interference is carried to such a pitch that we only know, by accident as it were, of the existence of a class till it asks to be examined.

Besides Glasgow, which I have already mentioned, the Halifax and Huddersfield classes have been examined, and have been very successful.

It is, I think, a great thing in its favour, that the present system can thus stimulate scientific instruction among the middle classes; stimulate it among the industrial classes and assist them to obtain it, and that, not on one particular plan, but according to the plans that different localities may adopt, comprehending plans so very dissimilar, as the Bristol Diocesan Trade School; the Glasgow Secular School; classes in Mechanics' Institutes, as at Huddersfield; and classes held, as in the institutions in connexion with the East Lancashire and Cheshire Union of Mechanics' Institutes, and the Cornwall and Devon Miners' Associations, in different places but taught by the same teacher. And this could only be attained by confining our attention to and paying on results.

As these classes prosper, as classes and schools are established in the direction which I have indicated, whether poor schools or schools for the middle classes, it is not too much to expect that they will find means, even if Government does not, to send their most promising pupils to complete their education at the School of Mines in Jermyn Street, or other similar institutions where scientific instruction of the highest class may be obtained. We may look forward to a constant supply of highly efficient teachers. To a spread of sound information among all classes of society, and to an increasing application of high scientific knowledge to the various industries of the country, and the establishment of special or technical schools of the nature of the trade schools of the continent.

I have already taken up so much time with the Science classes, that I can say but a few words with respect to the Navigation schools; but having entered so fully on the system of payments on results, which, as you will see from the new Minutes, is also adopted in these schools, there is hardly occasion for more.

Some years ago the officers of the mercantile marine were compelled to pass examinations, conducted by examiners in connexion with the Board of Trade, before they were allowed to take charge of ships as masters and mates. The fees from these examinations amount to a large sum per annum, more, in fact, a good deal than is at present spent in Navigation schools. It was, therefore, considered right, not only as the masters and mates paid so much, but also from the great importance that is rightly given to our Navy, both Royal and Mercantile, that an endeavour should be made to give them sound instruction, not merely to pass the required examination, for that is generally done by mere cram—forgotten as soon as over—but to give them some real insight into and understanding of their work: to educate boys for the sea: and to give sailors an opportunity of improving themselves when on shore.

Many Navigation schools were established at the different ports under this department. As I before stated the system was re-organized in July 1859.

By the Minute then passed, there were four groups or subjects laid down in which the teachers were to take certificates; these are,



—1st, a general acquaintance with mathematics, without having passed, in which no further certificate can count; 2nd. General navigation and nautical astronomy; 3rd. Knowledge and use of instruments; 4th. Physical geography.

There are nine different grades of certificates depending on the amount of knowledge possessed by the teachers of these groups, and they carry with them certificate allowances varying from 40*l.* to 120*l.* per annum.

The Interpretation Minute lately passed shows how these certificate allowances may be earned. Simply by payments on results, that is, by the master receiving 6*l.*, 4*l.*, or 2*l.* for every boy he has taught for a year or more, who passes an examination before the Navigation Inspector (on the success in which the amount depends), and, who is finally proved to have been apprenticed on board a merchant vessel or entered on board a man-of-war. And by his receiving 1*l.* for every seaman or mate who, having been taught by him, passes an examination for a higher grade certificate than that he previously held.

To the schools contemplated in the Minute of the 14th July, evening Navigation schools have now been added, as you will see by the new Minute on evening Navigation schools. These are for seaman and apprentices who wish to improve themselves while their vessels are in port, and who cannot attend during the day,

The attainments of the teacher are of course not required to be very high, and the certificate allowances attached to the three grades of certificates—20*l.*, 15*l.*, and 10*l.*,—are earned by the attendance of a certain number of bonâ fide sailors during the year; that is, the teacher receives 10*s.* per head of the average number attending during 200 evenings in the year. The amount under this head being limited, as in the case of the science certificate allowance, by the value of the certificate. There are also further payments for prizes taken by the pupils, 5*s.*, 10*s.*, and 1*l.*, according to the grade of the prize.

The system is so much like that for Science classes that I need not trouble you further; 'although the subject of instruction in Navigation Science is of the greatest importance and worthy of all attention, as through such instruction alone can be attained an object we must all have at heart, the retention of the supremacy of the sea in the peaceful, that is, the scientific aspect of that supremacy, by our sailors continuing the first in the world in intellectual attainments, not less than in those other qualities for which they have ever been celebrated.

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